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ECONOMIC GEOLOGY

VOL. XIX. APRIL–MAY, 1924. NO. 3

THE TIN DEPOSITS OF CHACALTAYA, BOLIVIA.

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Introduction.—Thus far fluorite has not been recorded from the cassiterite veins of Bolivia. The account here given describes a district in which this mineral forms an essential part of the vein filling.

It is interesting to recall that tourmaline, once supposed to be absent from the Bolivian veins, has lately been found in abundance in certain districts. Apatite, long ago mentioned by Domeyko from Colquechaca, has been observed by Davy [1] in altered rocks near veins, and has lately been noted by Hess [2] as quite common in veins in granite from Caracoles and Pacuni.

Topaz, still another of the minerals characteristic of the "normal" type of tin veins, has been found by Davy [3] as part of the mineralization of certain districts. Quite lately George H. Hall [4] has confirmed these observations and recorded apatite and topaz from several other localities.

Thus the evidence has been gradually accumulating that at least one of the types of the cassiterite veins of Bolivia conforms very closely to the deposits of Cornwall and Saxony.

Location and Geology.—Any one intending to investigate the

[1] Davy, W. M., "Ore Deposition in the Bolivian Tin-Silver Deposits," ECONOMIC GEOLOGY, vol. 15, 1920, p. 489.

[2] Hess, F. L., "Some Unique Bolivian Tungsten Deposits," *Eng. and Min. Jour.*, vol. 112, pp. 492–499, Sept. 24, 1921.

[4] Hall, G. M., "Paragenesis of the Bolivian Silver-Tin Ores," Geological Society of America, December Meeting, 1923.

[3] *Op. cit.*

Bolivian tin deposits will probably make La Paz his first station. Well known and easily accessible veins are found on the slopes of the snow-covered peak of Huayna Potosi, at Milluni, about fifteen miles north of the capitol. These veins occur in slate, not far from the contact with granite. There is, however, a district which lies still nearer to La Paz—about nine miles north of this city—and which can be very conveniently visited in a day's trip. I have found no reference in the literature to this district except some notes in Stelzner's paper,[5] evidently referring to some gold-bearing veins unknown to me.

The city of La Paz lies in a valley 1,000 feet deep, scooped out by the headwaters of the La Paz River in the Quarternary sands and gravels of the High Plateau or "Altiplano." One may ascend in comfort by automobile to the rim of the altiplano, to the lighthouse built to guide the inhabitants of the foggy uplands to the capital city. Then the traveller follows the rim for a few miles, meanwhile enjoying a panorama of rare beauty, limited on the east by the giant Illimani chain, deeply covered by dazzling snow fields. It now becomes necessary to change to mule-back, and a gradual ascent over slopes with heavy morainal material leads to an elevation of about 15,000 feet where one looks up to the main divide of the Cordillera Real across the headwaters of one of the eastern tributaries to the La Paz River. In this depression and on the slopes of the main range lies the Chacaltaya district.

The country rock is a black slate, probably of Devonian age, with a constant southwest dip of from 14° to 26° parallel to the gentle ascent to the divide, which here at a low pass attains an elevation of about 16,000 feet. Numerous granite blocks are scattered about the vicinity and a short distance to the north an area of intrusive granite appears; whether it is isolated or connects with a larger area to the east was not investigated. If the main range at this place contains granite this rock must occupy the eastern slope of the divide. The elevation at the mill was given by the officers of the company as 4,462 m. (14,440 feet).

[5] *Zeitschrift der Deutschen Geol. Gesell.*, vol. 49, 1897, pp. 51–142.

The Veins.—The district is apparently extensively mineralized though the veins are remarkable more for number than for production. The output of tin is certainly small, but a considerable amount of tungsten ore has been extracted.

Twenty veins are said to exist on the property of the Cia. Estañifera de Chacaltaya. Most of them strike east and west and dip steeply north or south. The width ranges from a few centimeters up to one meter; the lowest workings are 500 feet above the mill; the highest, like those of the Veta Hierro and the fluorite vein, range up to 2,000 feet above the office of the company situated near the bottom of the valley. The lowest vein has been worked principally for wolframite but contained also a little cassiterite. It has been opened for a vertical distance of a few hundred feet by short adit tunnels, the workings being now inaccessible.

The present explorations are confined to the Veta Hierro. This is opened by a tunnel driven by hand and a few hundred feet long and other more superficial openings. The country rock is black slate with some beds of quartzite. The narrow vein is at places rich in cassiterite. The ore is hand sorted and the intention is to convey it to the small mill by a tramway. On the fluorite vein which lies farther north and at a higher elevation no work is done at present.

For hospitality and much information I am indebted to the manager and engineer, Messrs. H. G. Schubert and Otto Lohse.

There are many other prospects in the vicinity, but the veins in general are swelling and contracting, and the ore is spotty. I have it on the authority of Mr. Maximo Nava of Uncia Mine that there are many tin prospects in the granite area to the north which carry tourmaline.

The Ore.—As far as observed the ore forms a filling of open fissures; in part it is massive, in part it has pronounced comb-structure by radial quartz crystals up to 8 centimeters in length. There appears to be very little alteration in the adjoining country rock.

The fluorite vein carries massive, white, or iron-stained ore

with occasional small drusy cavities in which quartz crystals project. This ore consists of a ground work of milky quartz crystals up to 2 centimeters in length to which are attached small crystals or crystalline masses of dark brown cassiterite. The principal and distinctly later gangue mineral is a white fluorite, in large crystalline masses, the individuals being often two centimeters in width. The fluorite fills in the interstices and cements the earlier crystals to a massive ore. The latest mineral is pyrite, which occurs in small cubes or irregular masses replacing the earlier minerals and particularly the fluorite.

Needles of tourmaline are found in the pyrite and in the cassiterite, more rarely in the quartz. The succession is thus: (1) quartz; (2) cassiterite; (3) fluorite; (4) pyrite, while the deposition of tourmaline in small quantities proceeded at least during the later and larger part of the mineralizing period.

The ore from the Veta de Hierro is more varied in composition. It is richer in cassiterite, contains more tourmaline and less fluorite than the material described above.

One specimen from the upper tunnel on this vein shows next to the wall a few centimeters of drusy quartz, on which is developed a quartz comb, the individual crystals reaching 6 centimeters in length. Between them and somewhat later are crystals of almost black cassiterite, on which are rosettes of a white mica corresponding to lepidolite, except that it contains no lithium. It is presumed that the lithium has been leached as the specimen shows much limonite between the quartz crystals.

Another specimen shows at the base a thin crust of quartz with a few tourmaline needles. Above this lies five centimeters of granular quartz, brownish or greenish in places from admixed fine tourmaline needles. There are also a few grains of pyrite and chalcopyrite, the exact place of which in the paragenesis is not certain. A little fluorite is present in this layer. The top crust, three centimeters thick, is composed of fibrous brown tourmaline in slender, straight fibers. With this tourmaline are a few quartz crystals and specks of pyrite.

A third specimen shows at the base two centimeters of coarse

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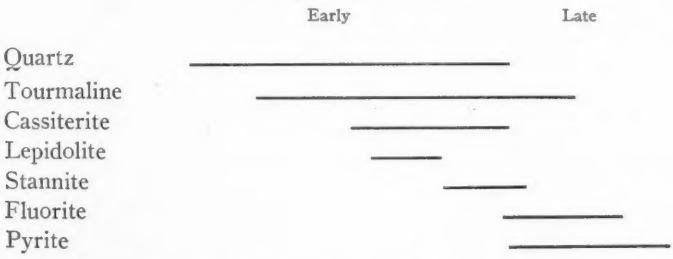
crystalline quartz, surmounted by a layer of green massive quartz, about one centimeter thick. The green color is caused by fine slender tourmaline needles of green color, embedded in the quartz. Above this follows several centimeters of massive quartz mixed with aggregates of dark brown cassiterite. Near the top this contains small aggregates of iron black, granular stannite, and it is covered by a last crust of quartz, only a few millimeters in thickness.

A fourth specimen consists of a drusy mass of white quartz and green, tourmaline-bearing quartz, irregularly mixed, further small crystals of cassiterite and much interstitial fluorite. There are many solution cavities coated with delicate crusts of light green tourmaline needles. In large part these cavities result from the solution of the fluorite which leaves the slender needles of tourmaline attached to or projecting from the quartz crystals.

Needles of tourmaline are found in quartz, in fluorite and in pyrite.

The following succession is clearly established:

PARAGENESIS OF MINERALS.



According to Beck[6] the general succession in tin-bearing veins is as follows: Lepidolite, Quartz, Topaz, Cassiterite, Arsenopyrite, Fluorite.

In the same volume (p. 289) the succession at Ehrenfriedersdorf, Saxony is as follows: Topaz, Wolframite, Cassiterite, Arsenopyrite, Quartz I, Apatite, Chlorite, Pyrite, Quartz II.

[6] Beck, R., "Lehre von den Lagerstätten," vol. 1, 1909, p. 255.

Davy [7] determines the general succession in Bolivia as follows: Tourmaline and Topaz, Pyrite, Arsenopyrite, Quartz, Cassiterite, Bismuth, Bismuthinite, Cylindrite and Franckeite, Stannite, Sphalerite, Chalcopyrite, Tetrahedrite, Jamesonite, Ruby silver.

Hall [8] gives the following succession for Bolivia: Tourmaline, Topaz, Apatite, Quartz, Pyrite, Arsenopyrite, Cassiterite, Wolframite, Chalcopyrite, Sphalerite, Complex sulphides.

Many of the differences are of course caused by the overlapping of the periods of formation of many minerals. The present case agrees in the main with the first table given by Beck, and seems to differ from the succession given by Davy and Hall (1) in the fact that quartz here is the earliest mineral; (2) in the very long period of formation of tourmaline; (3) in the fact that pyrite here is one of the youngest minerals whereas it usually in Bolivia precedes cassiterite. Davy's table indicates, however, that both pyrite and quartz continued to be deposited, in smaller amounts, beyond the close of the cassiterite period.

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Mass. Institute of Technology.

[7] *Op. cit.*
[8] *Op. cit.*

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APPARATUS FOR THE MEASUREMENT OF TEMPERATURES IN DEEP WELLS BY MEANS OF MAXIMUM THERMOMETERS.[1]

C. E. VAN ORSTRAND.

Introduction.—The determination of the temperatures of the rocks at great depths in the crust of the earth has been a subject of somewhat random investigation for almost two centuries. In or about the year 1664, Kircher[2] noted the increase of temperature with depth. Among the first observations are those by Gensanne[3] in 1740 in the mines of Alsace. The results of a great number of observations made since that time are conveniently summarized by Prestwich,[4] Koenigsberger,[5] and the Committee on Underground Temperatures of the British Association for the Advancement of Science. The instruments used in making the observations were generally of a tentative character, applicable only under the conditions imposed by that particular test. The increasing demand[6] for deep earth temperature data justifies the development of apparatus which can be used in making a geothermal survey on the same basis of accuracy and efficiency that levels and transits are used in making a topographic survey.

1 Published with the permission of the Acting Director of the U. S. Geological Survey.

2 Kircheri Athannasii, "Mundus Subterraneus," vol. II., 1678, pp. 184–5; quoted by Bischof Gustav, "Physical, Chemical and Geological Researches on the Internal Heat of the Globe," vol. 1, London, 1841, p. 182.

3 Prestwich, J., "Collected Papers on Some Controverted Questions of Geology," Macmillan & Co., 1895, p. 169.

4 *Idem*, p. —.

5 Koenigsberger, J., and Mühlberg, M., "On Measurements of the Increase of Temperatures in Bore-Holes; with the Depth, the Technics, and practical Importance of the Same for Geological Prognosis, with Reference to new Measurements in Mexico, Borneo, and in Central Europe." Trans. Inst. of Min. Eng., vol. 39, 1909–10, pp. 617–644.

6 See for example, Sayles, Robert W., "The Dilemma of the Paleoclimatologist," *Am. Jour. Sci.*, vol. III., June, 1922, p. 466.

Historical Note.—Excellent preliminary work has been done by Kelvin, Hallock, Jenkins, Darton and others.[7] The latest contribution is by Johnston and Adams[8] who used an electrical resistance thermometer attached to a heavy cable which was lowered into the well by means of the oil well machinery. I have since made a number of tests[9] to a depth of 3000 feet in wells located in the oil fields of West Virginia, using an electrical resistance thermometer in connection with a hand operated machine.

Mercurial Thermometers.—Electrical methods are of limited application in the field for the reason that it is difficult to construct suitable insulation for the leads; the maximum thermometer seems to be the only instrument which meets all of the requirements of general field service. The thermometers[10] are graduated at intervals of 1° Fahrenheit from 32 to 212° F. over a length of about 18 centimeters. The total length is about 21 centimeters; diameter of stem 6–7 millimeters. The accuracy is of the order of magnitude of 0.1 to 0.3 or 0.4° F. Temperatures in excess of 100° F. are best determined with a thermometer of the same general description, but graduated only from 100 to 212° F. over a length of about 10 centimeters, the bulb being placed just beneath the constriction so as to obtain a mercury column of minimum length. The short thermometer is preferable to the long one with an inverted bulb used first by Kelvin and later by Hallock. It would probably be more satisfactory to use two sets of thermometers; the first graduated from 32 to about 150° F.; the second from 100 to 212° F. There are two obvious advantages of the short mercury column—first, the stem correction is a minimum, and second, a very considerable

[7] White, I. C., "Discussion of the Records of Some Very Deep Wells in the Appalachian Oil Fields of Pennsylvania and West Virginia"; Van Orstrand, C. E., "Temperature Measurements," West Virg. Geol. Surv., County Reports, 1918, pp. 1–79; Darton, N. H., "Geothermal Data of the United States," Bull. 701, U. S. Geol. Surv., 1920.

[8] Johnston, J., and Adams, L. H., "On the Measurement of Temperature in Boreholes," Econ. Geol., vol. XI., 1916, pp. 741–762.

[9] *Idem.*

[10] Manufactured by H. J. Green, 1191 Bedford Ave., Brooklyn, New York; The Taylor Instrument Co., Rochester, New York; and other firms.

impact is required to force the mercury through the constriction into the bulb. The Fahrenheit scale is used for convenience in the field and also to provide a direct comparison of the computed mean annual temperatures with the observed values tabulated by the U. S. Weather Bureau in the volumes on Climatological Data.

Requirements of Apparatus for Use in the Field.—Conditions under which tests in the field are made vary greatly. In the usual drilling well of the standard rig type, the casing generally ends on the level of the floor or a few inches above it. Some wells are provided with casing heads or pipe connections that stand two or three feet above the floor. In others, pumping wells for example, the entire rig, including the floor, may have been removed leaving nothing other than the end of the casing projecting above the ground. All of these conditions must be taken into account in designing apparatus for general field use. Safety in transportation and convenience in operation in the field are likewise highly important factors which require careful consideration.

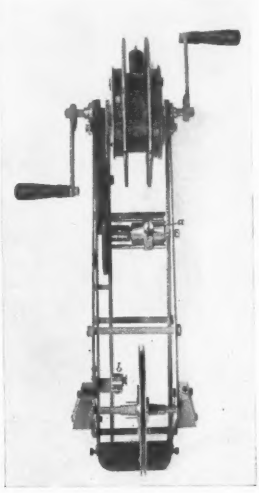

FIG. 25. Top view of hand-operated machine. (Weight, 52 lbs., 23.6 kgs.)

Apparatus for Lowering Mercury Thermometers into Deep Wells.—Fig. 25 shows top view; Fig. 26 *a* and *b* shows both end

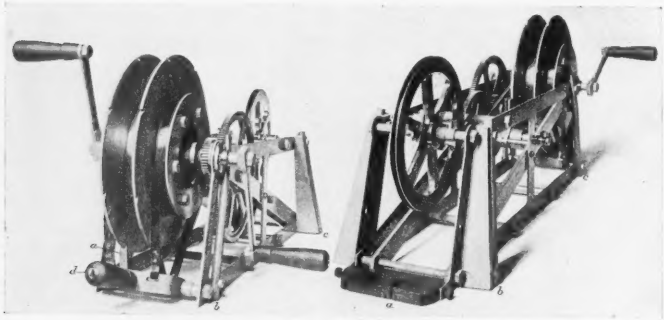

FIG. 26 *a*. (Left), rear and side view; *b* (right), front and side view of hand-operated machine.

and side views of a hand-operated machine which I have used quite extensively to lower maximum thermometers into wells to depths ranging from 500 to 4320 feet. Greater depths can be reached if the wells are clean and vertical. Dimensions of the apparatus are shown in Fig. 27 and 28.

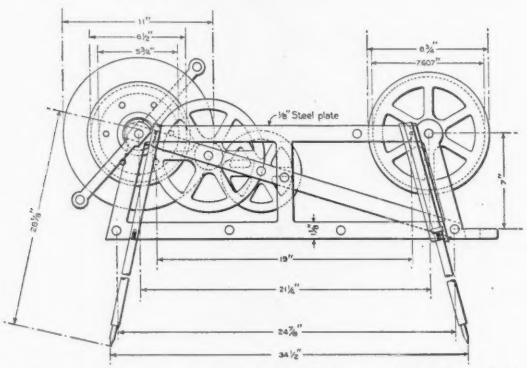

FIG. 27. Side view of hand-operated machine. (Weight, 58 lbs., 26.3 kgs. Weight of 1,000 ft. of no. 20 steel wire, 2.7 lbs., 1.2 kgs.)

The steel reel carries about 9,000 feet of number 20 B and S gage, polished steel piano wire, a quantity quite sufficient for a field trip of several months duration. Portions of the wire are

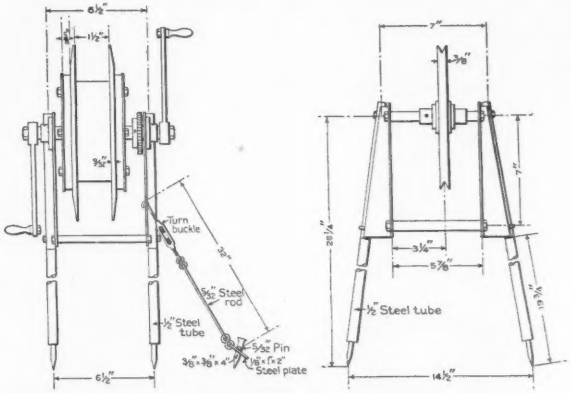

FIG. 28. End view of hand-operated machine.

rejected as they show signs of serious rusting. The axle of the reel consists of one solid piece of steel on which shoulders are turned for the attachment of the steel plates by means of bolts. The ratchets at (*a*), Fig. 26, fit into the notches on the rims of the plates and serve to lock the reel at any desired depth of the thermometer. The brake consists of a handle and two pieces of ½ inch steel tape, each of which incloses a disk of compressed fiber, ⅝ inch x 6½ inch. A small brass weight is attached to the eye (*d*) Fig. 26 *a*, at the end of the handle and serves to keep the reel under control and prevent accidents. The brake with weight attached is very useful for lowering thermometers into the well. The surfaces of contact between the tapes and the plates of compressed fiber are kept well oiled with kerosene, and the operator controls the speed by slightly raising and lowering the handle.

After leaving the reel, the piano wire passes through the slot in the vertical post (*a*), Fig. 25, and thence over the grooved measuring wheel into the well. Two pins projecting from the

sides of the measuring wheel operate a revolution counter (*b*)[11] which records the depths in feet. The vertical post distributes the line on the reel, otherwise the coils slip over each other, thus transmitting an impulse to the line which seriously disturbs the mercury column in the thermometers. The uniform reciprocating motion of the post is produced by a cylindrical cam,[12] 1¼ inch in diameter, having a right- and left-hand groove, with a zero period of rest. The groove has a pitch of two turns per inch. The gears are number 20 pitch, ⅜ inch face; the number of teeth beginning with the gear on the main axle as shown on Fig. 25, is 40–160–40–120.

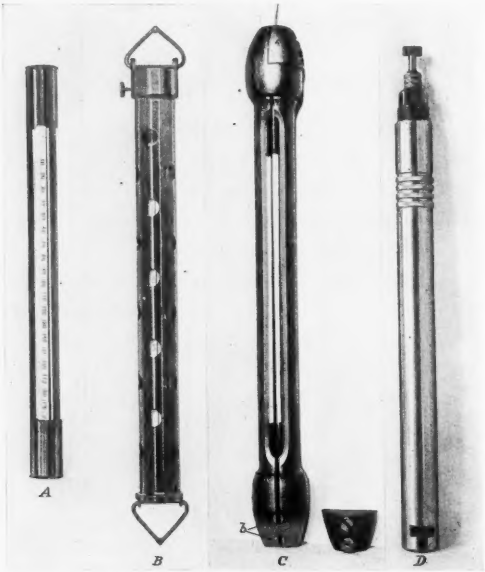

FIG. 29. Thermometer holder with three thermometers, and thermometer containers. (Weight, A, 5 oz., 142 grams; B, 7 oz., 198 grams; C, 1 lb., 454 grams; D, 18 to 25 oz., 510 to 709 grams.)

[11] Star No. 7, Veeder Manufacturing Co., Hartford, Conn.

[12] Schwamb, P., and Merrill, A. L., "Elements of Mechanism." John Wiley & Sons, 1904, p. 71.

The steel frame is supported on steel tubes ½ inch diameter by about 20 inches length, screwed into the short tubes (*b*) (*c*) Fig. 26 *a* and *b* which are attached permanently to the frame. Extra lengths of the tubes are used when needed. Four ⅛ inch steel rods, one of which is shown in Fig. 28, hold the frame in a fixed position on the floor. Final adjustment is made with the turnbuckles. Cheesecloth wrapped around the wire and attached to the small board (*a*), Fig. 26, serves to clean the wire as it is removed from the well.

In order to avoid delay in making a test, the weight of the thermometer holders and containers should be reduced to a mimimum consistent with the strength necessary for operation with safety. A holder consisting merely of two thin plates (3/32 x 25/32 inch, 6 thin-walled copper tubes (5/16 inch outside diameter), and three wires is shown on Figs. 29, *A*, and 30, *A*. Cot-

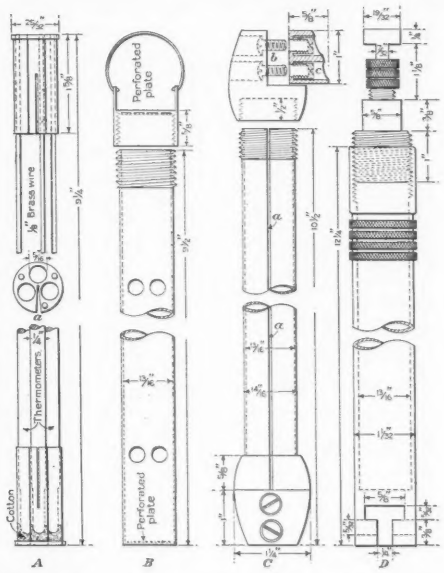

FIG. 30. Drawings for thermometer holder and containers shown in FIG. 29.

ton is forced into the tubes against the upper and lower ends of the thermometers. A V-shaped slot in the brass plates, shown at (*a*), Fig. 30, *A*, permits the steel piano wire to pass longitudinally through the center of the frame. This holder carries three thermometers and is used in the containers *B*, *C*, *D*, Figs. 29 and 30. In other words the holder is a unit which fits into each of the devices for lowering thermometers into a well.

The first container, *B*, Figs. 29 and 30, is merely a thin-walled brass tube with screw cap and attached bails. It is lowered into the well on an ordinary cotton line about ¼ inch diameter and is oftentimes very convenient for testing the temperatures at a depth of 100 feet when the well is free from water at that level.

Fig. 29, *C*, shows a brass container for use in exposing the thermometers directly to the air when attached to a piano wire. Fig. 30, *C*, shows a slightly different form of the same container in which the three wide slots have been replaced by a single narrow slot in a thin-walled tube. Slot (*a*) of the holder, Fig. 30, *A*, is placed in line with slot (*a*), Fig. 30, *C*, of the container, so that the piano wire passes through the center of the tube and the slotted screws shown at (*b*), Fig. 30, *C*, and at the bottom of Fig. 29, *C*. This form of container has the advantage of possessing a minimum weight, the thermometers are exposed directly to the air, and the time required to attach and remove the instrument from the line is not excessive. A clamp which utilizes the principle of a lever passing a center or of a cap with a tapered thread, may perhaps be superior to the device here described. Wire guides like those shown in the upper part of Fig. 31, *C*, Fig. 32, *B*, attached at the upper and lower ends of the brass tube Fig. 30, *C*, minimize the effects of impacts and, to a certain extent, prevent the adhesion of the line to the wall of the casing.

A steel container for use in wells containing oil or water is shown in Figs. 29 and 30, *D*. The T at the top of the figure and the slot at the bottom are the same as those shown in Fig. 31, *D*, *E*, *F*. This container can be attached at the end only of the line, but the one shown in Fig. 31, *A*, can be attached at any point. It consists of three steel tubes soldered together at the ends, except

that a slot (*a*), Fig. 31, *A*, is retained for the insertion of the piano wire, the same as at (*a*), Fig. 30, *A*. This combination of three tubes, each carrying one thermometer, is placed in a tube of the same design, except for dimensions (about 1 1/16 inch inside diameter) as that shown in Figs. 29 and 30, *C*.

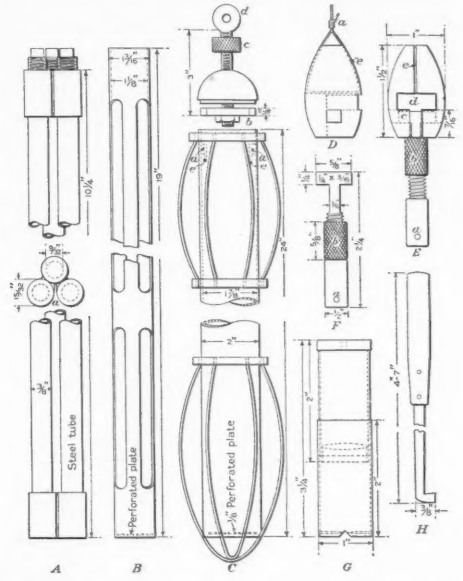

FIG. 31. Thermometer containers and other pieces of apparatus. (Weight, A, 11 oz., 312 grams; B, 11 oz., 312 grams; C, 5 lbs., 2.3 kgs.)

The small ellipsoidal piece of brass, Fig. 31, *D*, is attached to the end of the line by first giving the wire a couple of turns in the groove (*e*), and then winding the wire around itself as shown at (*a*), Fig. 31, *D*. In operation, the sleeve (*b*) is turned downward into its lowest position, Fig. 31, *F*, after which the T is placed in the slot (*d*), Fig. 31, *E*, so that its axis coincides with the vertical axis of the ellipsoidal piece of brass. The T is then lowered into the slot (*c*), and the two pieces connected rigidly

together by turning sleeve (*b*) upward until it presses with considerable force against the lower surface of the truncated ellipsoid. This simple device meets all of the requirements of safety and convenience in the field. The same principle is utilized in the

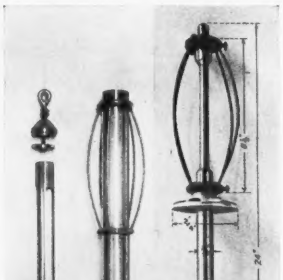

FIG. 32. Brass tube and solid brass weight. (Weight, A, 11 oz., 312 grams; B, 5 lbs., 2.3 kgs.; C, 7 lbs., 3.2 kgs.)

design of the device for the attachment of the hemispherical cover to the top of the brass tube, Figs. 31, *C*, 32, *B*. Two slots in ring (*a*), diametrically opposite each other, permit the ends of the T-plate (*b*) to pass perpendicularly through the ring and below the lower ends of the four pins or metal projections (*e*) placed near the edges of the slot; the T is then rotated slightly to the right or left, and pulled upward until its upper surface bears on the lower surface of the ring. Sleeve (*c*) Fig. 31, *C*, is then lowered until it presses firmly against the top of the hemispherical cover. This device, like the preceding, is both safe and convenient; it also prevents the entrance into the tube of mud and water from the wall of the casing.

The brass tube, Figs. 31, *C*, 32, *B*, serves a two-fold purpose—first, it is used as a weight on the end of the piano wire and second, it serves as a container for thermometers lowered into the well on the sand line. When used as a weight, one end of a ⅛ inch stranded bronze wire about 10 feet in length, is attached to the eye (*d*), and the other end to the eye (*a*), Fig. 31, *E*, *F*, of the T-connector. If the well contains no water at the level to be tested, the T-connector is attached to the ellipsoidal bob, Fig. 31, *D*, otherwise the steel tube, Figs. 30, *D*, 29, *D*, is connected to the bob, and the T-connector attached to the bronze wire is inserted in the slot at the bottom of the steel tube. The T-connector is not needed when the large tube, Figs. 31, *C*, 32 *B*, is used as a container for the thermometers. The end of the bronze line is then fastened to the dart on the end of the bailer. Two ⅛ inch stranded bronze wires about 12 feet in length are used for this purpose. If the well contains no water at the point to be tested the holder, Figs. 29, *A*, 30, *A*, is placed in the middle of the tube, Figs. 31, *B*, 32, *A*, between two columns of cotton each about 6 inches in height. Similarly, this tube is placed in the large tube, Figs. 31, *C*, 32, *B*, each end of the large tube being packed with cotton to a height of 5 or 6 inches. Tests in water are made in the same way, using the steel tubes, Figs. 29, *D*, 30, *D*, and 31, *A*. A device of this kind will generally dampen severe impulses transmitted to the sand line by the slipping of the coils on the reel. It is sometimes undesirable to lower the large tube containing the thermometers below the casing. The containers, Fig. 31, *A*, and Fig. 30, *B*, *C*, *D*, may then be wrapped in wire screen and placed in the top of the bailer, or they may be inserted in a slot cut in a block of wood about 2 inches in thickness and bolted to the dart of the bailer. The latter method obviously has the advantage of placing the thermometers almost directly in contact with the rocks.

The depth recorder, Figs. 33, 34, is used to measure the depths to which thermometers are lowered on the sand line. The pins (*c*) operate a revolution counter (*d*) which records the depth in feet. The idlers (*b*) in connection with the spiral springs

serve to keep the large measuring wheel in contact with the line. The steel frame is mounted on steel tubes, attached to the floor as previously described. (See Figs. 25–28.) No attempt has been

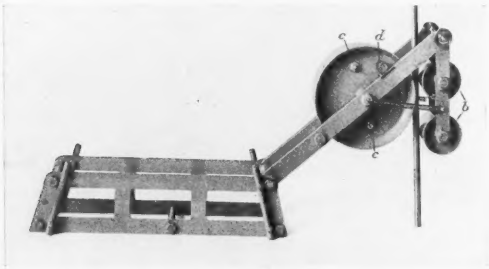

FIG. 33. Depth recorder. (Weight, 25 lbs., 11.3 kgs.)

made to produce a finished machine. If extended service is required, the measuring wheel should be mounted on ball bearings and the rim, case hardened. Gears should be used to operate the

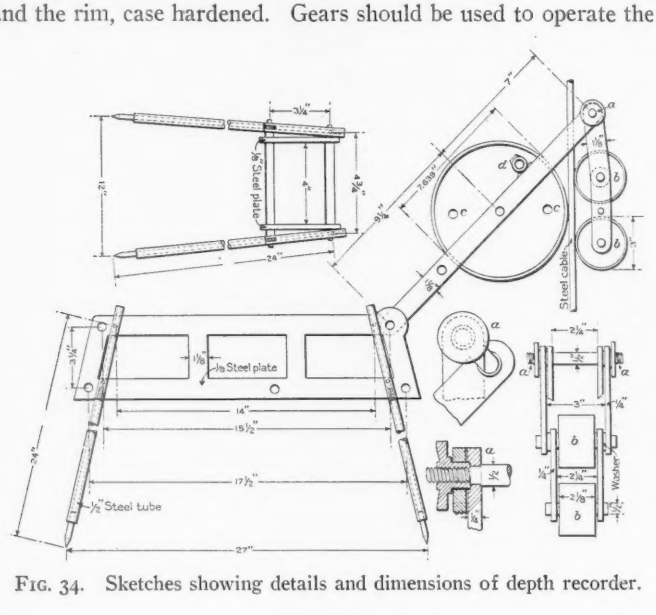

FIG. 34. Sketches showing details and dimensions of depth recorder.

revolution counter otherwise it may lag slightly behind the wheel, and there is also the possibility of making an error of one foot at the beginning and end of the count.

Some Practical Suggestions.—Experience is an important factor in making temperature tests in deep wells. Rule of thumb methods can not be used for various reasons. In the first place, conditions in the field are not on a laboratory basis—the observer is frequently at a serious disadvantage on account of weather conditions, awkward arrangements at the wells, such as pipe connections, the absence of a floor, no means of protecting thermometers from the heat of the sun, and so on; some wells are crooked; not infrequently the casing is covered with mud, grease, or paraffin, to such an extent that it is impossible to lower the thermometers to any considerable depth. Flows of oil, gas and water sometimes introduce complications in the depth temperature curves which are very difficult of correct interpretation, thus causing confusion to the observer while the test is in progress. The following suggestions are made to assist the beginner in overcoming the more formidable obstacles.

Rather curiously the 100-foot level is oftentimes the most difficult point to test, due to the fact that the surface temperature may greatly exceed the temperature to be measured. This difficulty can generally be avoided by making the observations in the early morning hours, or better still, by leaving the thermometers in the well over night, and removing them early in the morning—they can then be inclosed in thin-walled sealed tubes like those shown in Figs. 30, *D,* and 31, *A,* which prevent all possibility of temperature changes while removing them from the well.

A small parachute consisting of a piece of felt attached to an open wire ring about 2 inches in diameter is a useful protection to the thermometers when testing at depths ranging from 100 to 1,000 feet or more. The thermometers are brought to the 100 foot level, and the parachute which has been chilled in ice water, is placed over the mouth of the hole, the piano wire passing through the center of the ring. The tube containing the thermometers is thus automatically wrapped in an ice chilled cloth,

immediately upon its arrival at the top of the well. An ice bath about 4 inches x 4 inches x 8 inches made of galvanized sheet iron and encased in felt is needed for chilling the thermometers. In the bath are placed several thin-walled brass tubes, 7/8 inch in diameter by 9½ inches in length. A block of metal of sufficient weight to keep the tube in a vertical position when placed in water is soldered into the bottom of each tube. These tubes make a convenient receptacle for the thermometers when mounted in the holder, Figs. 29, *A*, 30, *A*; they prevent breakage and the thermometers are kept dry. Sufficient cotton is placed in the bottom of the tube to enable the observer to grasp the upper end of the holder and thus avoid possible disturbance of the mercury columns from the heat of the hand.

A simple centrifugal machine would be of great value in the field for use in adjusting the mercury columns. I have used instead a brass tube just sufficient in size to admit the thermometer holder, Figs. 29, *A*, 30, *A*. The brass tube is attached lengthwise to the end of a wooden handle. Occasionally a thermometer resists the lowering of the mercury to such an extent that the mercury can not be returned to the bulb by this method. It is then removed from the holder and adjusted by means of the hand. A thermometer of this kind should be reserved for use at great depths. The difficulty of adjusting the thermometers can be largely avoided by testing the different levels in order of depth, beginning at the top. An exception is made at the deepest level which is tested first so as to avoid the delay incident to adjusting the mercury columns, and also to ascertain the condition of the well, particularly with reference to the depth of standing oil or water.

An experienced operator judges the behavior of the apparatus in the well by the pull on the handles of the reel. The impulse transmitted to the handles by the impact of the large brass tube, Figs. 31, *C*, 32, *B*, on the surface of oil and water is oftentimes sufficiently intense to enable the operator to accurately locate the level of the fluid. Otherwise, cotton must be placed in the upper part of the brass tube, and the level of the water located by trial.

This information is indispensable for the thermometers can not be subjected to the pressure of any considerable depth of fluid without introducing errors in the temperature records and ultimately causing permanent injury to the bulbs of the thermometers. The sensitiveness of the apparatus could be increased by the addition between the wire guides of a couple of aluminum plates, about 4 inches in diameter. A slightly different device, Fig. 32, *C*, in which the brass tube is replaced by a solid brass rod, 7/8 inch x 24 inches, is an essential part of the apparatus. It can be used in wells of the usual diameter instead of the brass tube, while for wells in which the diameter is greatly reduced, say to 2 inches or less, the solid rod alone suffices. Set screws are used in attaching the plates and guides to the rod so as to permit of easy removal when the rod alone is used as a weight. The rod should be 7/8 inch in diameter throughout its entire length and not reduced in diameter within the space enclosed by the wire guides as shown in Fig. 32, *C*.

The steel tube, Figs. 29, *D*, 30, *D*, is easily and quickly attached to or removed from the end of the line by simple manipulation of the T-connector. The brass tube, Figs. 29, *C*, 30, *C*, can be placed at the end or any other point on the line; a number of them can be attached to the line at the same time so as to obtain readings at various depths in the same time interval. The number of records which can be obtained in a single lowering of the line depends chiefly on the skill of the observer. When the brass tubes are used, the mouth of the well is covered with a couple of small boards or, preferably, a thin brass disk (about 1/16 inch x 8 inches) with a slot to the center for the insertion of the piano wire. The plate serves to prevent tools from falling into the well and, in addition, is a convenient rest for the hand while attaching the tubes to the line or removing the same from the line.

Considerable difficulty is experienced by drillers in handling a steel tape in a well. For some reason, the tape adheres to the wall of the casing. The adhesion is generally attributed to magnetism. I am of the opinion, however, that this phenomenon is due chiefly to friction and to surface tension on the film of

moisture between the casing and the flat surface of the tape. Any line can be made to adhere to the casing by covering it with a thick layer of heavy lubricating oil. I have found that kerosene diminishes the friction between the piano wire and the casing; but the heavier oils increase it, oftentimes to a very considerable extent. In the field, the piano wire should be covered with a film of thin oil, such as kerosene, partly to prevent rust and partly to prevent adhesion to the casing. The number 20 piano wire which I have used seems to me to be the minimum in diameter which can be used with safety. Some advantage may perhaps be gained by using a number 19 piano wire and a correspondingly heavier weight on the end of the line. A very considerable increase in the weight, however, would necessitate the addition of gears to the axle of the reel.

The steel tube, Figs. 29, *D*, 30, *D*, may be made from either steel tubing or solid rods of machine steel. For depths in the fluid not exceeding 3,000 feet, the thickness of the wall of the tube can be reduced to 1/16 inch. The tube shown in the photograph, Fig. 29, *D*, is made of a steel that sells under the trade name of "cyclops." It is a nickel steel, non-corrosive and non-magnetic. Corrosion is a matter of some importance, but a tube made of machine steel will last for several years even when used in the salt water of the oil fields. The nonmagnetic property is doubtless of some value but, as just explained, it is probably of minor importance.

Considerable care and judgment must be exercised in handling the thermometers. The loss from breakage is a negligible quantity, but repeated exposure and lowering of the mercury into the bulb tends to weaken the bulb and constriction to such an extent that the thermometers may always register too low. To guard against this kind of error, one at least of the thermometers should possess a constriction which strongly resists the return of the mercury to the bulb. Agreement of the three readings is then an excellent criterion of accuracy. The final test is made by plotting the depth temperature curve on a large scale in the field.

Thermometers can be lowered at a velocity of about 200 feet

per minute. The maximum velocity permissible for removal is about 100 feet per minute. An exposure of 45 minutes is required for the steel tubes in fluid, and about 1¼ hours for the brass tubes, Figs. 29, *C*, 30, *C*, in which thermometers are exposed directly to the air. An exposure of three hours in air has been found sufficient when the thermometers are lowered on the bailer by any of the three methods previously described—the minimum exposure has not been determined. The time required obviously depends on the temperature at the given depth and the temperature of the air at the surface of the ground. One of the most potent sources of error in using the bailer is due to the sudden jerk transmitted to the sand line in starting the oil well machinery. Experienced drillers, however, soon learn to overcome this defect. Vibrations resulting from pulsations transmitted to the sand line by the engine are generally eliminated by changing slightly the speed of the engine.

All of the apparatus previously described has been designed with the object in view of keeping the thermometers in a vertical position from the time they enter the well until they are removed and the readings are completed. Three additional accessories are needed; first, the small hook, Fig. 31, *H*, made from the blade

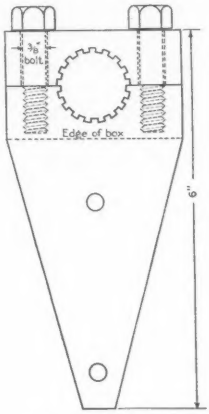

FIG. 35. Wrench.

of a hacksaw, serves to remove the holder, Figs. 29, *A*, 30, *A*, 31, *A*, from any of the containers; second, the wrench, Fig. 35, which is attached to one of the boxes used in transporting the apparatus, serves to grip the steel tube, Figs. 29, *D*, 30, *D*, about the milled edge while the plug is put in place or removed with an ordinary wrench; and third, the thermometers are read with a reading telescope, Fig. 31, *G*, which enables the observer to maintain the line of sight midway between the ends of the graduations and at right angles to the mercury column.

The best records are generally obtained by making the test just before the well is drilled into the pay sand. Drilling should be discontinued for at least one day before the test is begun. Records obtained immediately after drilling has been discontinued sometimes reveal rather marked irregularities.

Accuracy and Efficiency.—The difference between duplicate readings of maximum thermometers lowered into the well on the hand operated machine ranges from 0.1 to 0.3° F. The error probably exceeds this amount slightly when the sand line is used. I have no reason for believing however that the difference between duplicate readings ever exceeds 0.5° F., and ordinarily, it is certainly less than this amount. In many cases, the lack of temperature equilibrium in the well introduces errors which greatly exceed the error of observation.

The time required to test a 3,000-foot well with maximum thermometers varies from a little more than one day to two days. If readings are taken at intervals of 500 feet, the complete test can be made in about 10 hours. With sufficient experience in handling more than one set of thermometers on the line at the same time, the time required may be reduced to something like 8 hours, including observations at intervals of 250 feet.

When the bailer is used, depths are easily and accurately measured by means of the depth recorder, Figs. 33, 34. Three tests were made recently to a depth of 5,900 feet in deep well No. 1942, of The People's Natural Gas Company, located near Ligonier, Pennsylvania. The error of duplication in the first instance was 2 feet; in the second 6 inches. The precise error could not be

determined on account of the lag in the revolution counter as previously explained. With proper adaptation to commercial needs, an instrument of this kind would be more efficient and more accurate than the usual methods of depth measurement. It is important to note that friction between the line and the casing tends to reduce the measured length when the line is lowered into the well, and to increase it, on removal from the well. A difference of 1 or 2 feet is oftentimes recorded on the measured length of a piano wire when it is lowered to and removed from depths of something like 3,000 feet. The arithmetic mean of the two readings is obviously the best approximation that can be made to the true depth. Such refinement of depth measurement is not needed in making temperature tests—it is quite sufficient to measure the depth while lowering the thermometers into position.

General Conclusion.—For many purposes, such as the measurement of temperatures in mines and springs, and wells not containing oil and water, the thermal couple and the electrical resistance thermometer will undoubtedly prove to be very useful instruments. Only a very small proportion of the wells, however, which are available for temperature tests, are entirely free from oil and water; consequently, the electrical methods are not very satisfactory for general service such as one needs on a field trip. Although the maximum thermometer is an awkward instrument and somewhat unreliable unless handled with great care and skill, it is, nevertheless, the only instrument which meets all of the requirements of general field service; and with proper care and manipulation, it can be made to yield results of a high degree of precision. In isolated fields, where the oil well machinery is always available for raising and lowering the heavy cable, the electrical methods may prove to be a success, but considerable experimentation will be required to develop an insulation that will withstand the destructive action of oil and water. In the meantime, the accuracy and efficiency obtainable with maximum thermometers by the methods described in this paper are abundantly adequate to meet all the requirements of a geothermal survey.

Acknowledgments.—The design of the apparatus described in this paper is based on the experience gained in an extended series of tests in the field in which I have had the most generous co-operation of both officials and employees of a great number of the oil companies. Credit is due Mr. R. L. Atkinson, Mechanician of the United States Geological Survey, for the construction of the apparatus and for numerous valuable suggestions in regard to the design of certain details. I am especially indebted to Mr. John B. Corrin, Vice President of the Hope Natural Gas Co., and Mr. John B. Tonkin, Vice President of The People's Natural Gas Co., both of Pittsburgh, Pennsylvania, for their unusual contribution in placing a great number of wells of exceptional depth at my disposal. Several of these wells reached depths slightly less or greater than 7,000 feet and two of them, the Lake well at Fairmont, West Virginia, depth 7,579 feet, and the Goff well, Clarksburg, West Virginia, depth 7,386 feet, are the deepest wells in the world.

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RECENT PROGRESS WITH LEACHED ORE CAPPING.[1]

H. W. MORSE AND AUGUSTUS LOCKE.

Introduction.

In this paper we propose to try out, in three districts, estimations of sulphide copper from oxidized capping. We propose to offer samples of such capping; to make certain wide assumptions; to join these assumptions with the evidences which the samples, in their oxidized state, afford; to restore these samples, by these assumptions, to an inferred sulphide condition; and to check this condition against the known sulphide below, *as a prediction of copper quantity.*

Assumptions.

The assumptions apply to certain kinds of disseminated copper sulphide ores—that is to say, to sericitized, silicified rock, carrying, in specks and veinlets, a few per cent. of pyrite, chalcocite, bornite or chalcopyrite. The mixture of pyrite and chalcocite is the most common one.

Such ores consist chiefly of Si, Al, O, alkaline earths, alkalis, Fe, Cu, S. The corresponding capping consists chiefly of Si, Al, O and Fe, with varying amounts of Cu and with added water.

If we are to restore this capping to an inferred sulphide condition, we must find among these two groups of elements a skeleton or pattern common to both and related to copper quantity. The Si and Al are permanent enough. But their relations to copper quantity are inconstant. What, then, about the iron?

To be used, the iron needs the following three qualities:

1. It must be either permanent, or changed in a degree calculable from capping evidences.

[1] Society of Economic Geologists, New York Meeting, May, 1923.

2. Its ratio to copper must be calculable from capping evidences.

3. It must be separable, in the capping, into iron of sulphide and iron of non-sulphide source.

First, as to its permanence. Our field and laboratory evidences are reassuring; in those cappings which we have tested from an ancestry bearing not over five per cent. of pyrite and with an excess of precipitant such as feldspar, little iron is lost during oxidation. The iron is either *indigenous*—remaining within the room of its sulphide parent; or it is *gangue-precipitated*—soaked into kaolin, painted in cavities, or replacing calcite. If it travels at all, it makes halos about the sulphide voids, but leaves white, intermediary ground between the halos. It seldom bears the marks of long journeys. As a first assumption, then, let us conclude that the iron is sufficiently permanent.

But the iron must also maintain a ratio to copper calculable from capping evidences. Following are two hypothetical equations involving complete oxidation of all the elements in question:

$$(a)\quad FeS_2 + 2Cu_2S + 17\tfrac{1}{2}\,O = 4CuSO_4 + \tfrac{1}{2}Fe_2O_3$$

By weight, 1 Fe to 4.54 Cu

$$(b)\quad 2FeS_2 + Cu_2S + 20\,O = 2CuSo_4 + Fe_2(SO_4)_3$$

By weight, 1Fe to 1.1 Cu.

These, corresponding respectively to the ratios, one pyrite to two chalcocite, and two pyrite to one chalcocite, correspond also to the point at which all the copper, but none of the iron, may go into solution; and the point at which all the copper and all the iron may go into solution.

These points are critical. At the first, the copper is leached, but the iron may be retained as *indigenous limonite* in the place of the sulphide parent—a porous, weak body, occupying a fifth of the sulphide volume. At the second, both the copper and the iron may be *transported.*

Moreover, these points correspond to qualities determinable in the leached capping itself. Indigenous limonite is separable by inspection from limonite precipitated in gangue. If the sul-

phides were pyrite and chalcocite, and if the iron is wholly indigenous and the copper wholly leached out, the suggested ratio is one pyrite to two chalcocite. If the limonite is wholly transported and precipitated in gangue, the suggested ratio is at least two pyrite to one chalcocite.

And the fixation of iron and copper, or their escape from the sample during oxidation, may be confirmed by the present precipitating ability of the capping, as shown by laboratory experiment, in terms of iron and copper. For the probability of escape varies inversely with the reactiveness of the sample.

If, then, the assumed equations are applicable, the leached sample itself may be made to tell, within limits, the copper-iron ratio: whether it lies above 4.5 to 1; between 4.5 to 1 and 1.1 to 1; or below 1.1 to 1.

But do the substances react in these proportions? In order to do so, they must be unhampered at the time of oxidation by reactive gangue, though that gangue touch the sulphides. The fixation or transportation of copper and iron must be governed, not by gangue, but by the sulphides themselves. The destruction of the sulphide must have proceeded by *cloister oxidation.*

On apriori grounds, such oxidation of disseminated sulphides seems not improbable, because oxidation there tends to proceed through films of water, coating discrete sulphide grains and bathed on their outer surfaces by air. Let us, then, assume cloister oxidation.

But even with cloister oxidation, these equations are no more than chemical expedients. They can represent only a convenient approximation, for limonite precipitation is conditioned, not only by the ratio between acid and bases, but also by the ratio between ferrous and ferric ions and by the concentration of the solution.[2]

So far, then, we have made, as working hypotheses, apriori assumptions that the sulphide iron is fixed as limonite, and that its ratio to copper is, within limits, calculable from capping evi-

[2] E. Posnjak and H. E. Merwin, "The System SO_3, Fe_2O_3 and H_2O," *Jour. Am. Chem. Soc.*, Vol. XLIV., Sept., 1922.

dences. If we are to restore the capping to an inferred sulphide condition, we have still to separate the iron of sulphide from that of non-sulphide origin. For, in terms of copper, *total* iron will have no meaning.

Experience indicates that, in these ores, siderite is unlikely to occur, and it indicates, further, that the iron-bearing rock minerals other than sulphides (chiefly magnetite, hematite, biotite and chlorite) tend to survive oxidation unchanged and in a difficultly soluble form, and do not furnish significant limonite to the capping. And, therefore, the sulphide iron, having gone to limonite, may be approximated as that easily soluble in dilute hydrochloric acid.

In a capping, then, of appropriate qualities: it has endured sulphide enrichment; it has been subjected to the acid liberated by the enrichment and has started oxidation without "easily soluble" iron; its sulphide iron has become "easily soluble" during oxidation; it has had a ratio of pyrite to chalcocite of not over 2 to 1; it has oxidized without interference by gangue; its reactions are such that, with a pyrite-chalcocite ratio of 2 to 1 the copper and iron are all dissolved, while with a ratio of 1 to 2 the copper is dissolved but the iron is held: in such a capping, we can make shift to estimate the preoxidation content of copper.

THE DATA REGARDING THE SAMPLES OF CAPPING.

TABLE I.

DATA REGARDING THREE SAMPLES OF CAPPING.

	H_2SO_4 in 1% Solution: Ratio of Weight Neutralized by Capping to Weight of Capping.	Cu in 1% Solution: Ratio of Weight Precipitated by Capping to Weight of Capping.	Fe in 1% Solution: Ratio of Weight Precipitated by Capping to Weight of Capping.	"Easily Soluble" Fe.	Cu.
Ajo.....	7. %	1.3%	2.6%		2.08%
Miami.....	1.2%	trace	0.8%	0.5 %	trace
Tyrone.....	2. %	0.4%	1.9%	1.85%	trace

Ajo.—Limonite: chiefly indigenous, somewhat painted along cracks; none banded or botryoidal.

Copper: silicates and carbonates; partly indigenous as cavity and crack fillings; partly transported as crack fillings and as stains in gangue; distributed uniformly over large tonnages.

Miami.—Limonite: chiefly indigenous and subordinately as paint; none banded or botryoidal.

Tyrone.—Limonite: chiefly painting cracks or staining gangue in halos one to a few millimeters in diameter; in minor amount indigenous; little banded or botryoidal.

INTERPRETATION OF DATA (IN TERMS OF FORMER COPPER GRADE).

TABLE II.

RESULTS OF INTERPRETATION OF DATA.

	Inferred Sulphide Iron	Inferred Ratio Sulphide Iron to Copper.	Inferred Sulphide Copper.	Actual Sulphide Copper.	Remarks.
Ajo.....	—	—	2.08%	1.85%	Sample composed of about twenty pairs of specimens each including one sulphide and one capping specimen taken within a few feet of each other.
Miami...	0.5 %	4.5 to 1	2.25%	about 2.00%	Sample about same as at Ajo except that the adjacency of the members of each pair is less well established.
Tyrone...	1.85%	1.1	1.85%[3]	1.5–2.0%	Sample of capping from croppings of 160 acres of ground.

Ajo.—The uniform distribution of the copper, in considerable part indigenous, suggests that little copper has been lost; for field experience indicates that a partial, uniformly distributed leaching of copper is improbable. The precipitating ability for copper still possessed by the sample strengthens this conclusion.

If little copper has been lost, the sulphide carried copper in quantity about equal to that of the capping. Furthermore, the

[3] A correction of about 10% is made for reduction in specific gravity during oxidation.

sulphide could scarcely have undergone supergene enrichment, for copper was not released during oxidation. The sulphide then was hypogene; the copper was probably in the form of bornite or chalcopyrite with probably little pyrite. The inferred sulphide copper is 2.08 per cent.

Miami.—The indigenous character of the limonite shows that little iron was lost during oxidation. The absence of copper, except in traces, makes the leaching of copper seem probable.

Conceivably, iron could be fixed in the place of the sulphide by lime brought in the water. But such fixed iron, in the experience of the writers, usually makes a compact limonite pseudomorph, while this limonite is the fine sponge characteristic of the oxidation of bornite, chalcopyrite or mixtures of chalcocite or other copper-bearing sulphides with pyrite.

That the mixture was chalcocite and pyrite is suggested by relict sulphides existing in small quantity in the capping.

If, then, we assume the mixture to have been chalcocite and pyrite, we shall, according to our hypothetical equations, conclude the ratio to have been two molecules of chalcocite to one of pyrite; for, with more chalcocite, more copper would have been fixed, and with less chalcocite, more iron would have been transported. This gives, by weight, a ratio of copper to iron of 4.5 to 1.

Easily soluble iron in the sample is 0.5 per cent. That the sulphide carried no easily soluble iron at the start of oxidation seems probable because supergene enrichment is indicated and this would have furnished an acid bath to dissolve such iron.

The inferred sulphide copper is, then, 4.5×0.5 per cent. $= 2.25$ per cent.

Tyrone.—Relict sulphides suggest that the sulphide was chalcocite and pyrite.

The transportation of most of the limonite suggests a pyrite-chalcocite ratio at least 2 to 1. The indigenous limonite, existing in small amount, suggests that it did not greatly exceed 2 to 1. The occurrence of limonite halos attached to the voids formerly containing sulphide grains, suggests that iron was not lost dur-

ing oxidation. The probability of supergene enrichment involves the probability that no easily soluble iron existed in the sulphide at the start of oxidation.

The easily soluble iron is 1.85 per cent. If we take the ratio of 2 pyrite to 1 chalcocite, we have a ratio of 1.1 copper to 1 iron. This gives an inferred sulphide copper content of 2.04 per cent. But a correction of about 10 per cent. has to be made for decrease in specific gravity without volume change, during oxidation. This gives an inferred sulphide copper content of 1.85 per cent.

THE VALIDITY OF THE SAMPLES.

That the samples of capping were derived by oxidation from sulphide material equalling in copper content the samples of sulphide, is not proved. In Ajo and Miami it is rather probable because of the uniformity in the ore grade, the proximity of the sulphide and capping specimens to each other, and the close correspondence in position and size between the sulphides on the one hand and their indigenous, oxidized products on the other.

In Tyrone the sample is less certain; several thousand specimens of cropping were taken from a partly developed area of 160 acres which included scattered bodies of ore covered 100 to 500 feet deep by capping; of these specimens several hundred, constituting all those judged by us as having once been ore, were picked out to make the sample used in this paper. The actual sulphide grade taken is that of the known ore bodies, and its use as a check on our inferences necessitates correct distinctions between good cropping and poor, and accurate structural projection from the surface downward for between 100 and 500 feet.

CONCLUSIONS.

With a single new major process or variant, the rest being fixed and already successfully used, the chance of success in a new process such as a metallurgical development is good. With two new variants, the chance is poor. For the two new variants are two links subject to simultaneous change.

Here we have accomplished estimations of the sulphide copper that seem reasonable. But we have had to use, not one, but three, new variants. All must be sound if the method is sound. That all are sound and that all correspond to and define natural processes, we may not be so credulous as to believe. Natural systems are too unconventional for such apriori chemical definition and, that particular chemical equations, selected in preference to all competing equations, should, in fact, represent the vital thought, is improbable. We shall feel the danger of being comforted by plausibility. We shall require confirmation in a score of ore deposits and shall consider the possibility that single plausible results, such as those presented, mean accidental coincidence.

The closeness of the check between the copper content of the sulphide ore and the estimate made from the capping is probably accidental. But certain general field tendencies suggest that the method, nevertheless, has promise. In enriched, disseminated deposits, the total iron in the capping is, in general, equal to the iron in the ore; the readily soluble iron in the capping approximates the sulphide iron in the ore; and the criterion of limonite indigenousness, by no means a new one, is known to indicate a high ratio of chalcocite to pyrite. The ratio of pyrite to chalcocite in Miami ore is actually about 1 to 2, and that in Tyrone ore about 2 to 1.

The results suggest that, within a certain range of copper ores, the capping might eventually be made to yield, (in advance of exploration in sulphides) quantitative information regarding sulphide copper content.

San Francisco, Cal.

DISCUSSION

Mr. Loughlin: In the Eastern part of the Tintic Mountains there is an extensive area that has been leached almost a pure white through the weathering of latites, andesites and some rhyolites, originally containing disseminated iron and perhaps copper sulphides. A white skeleton of silica now remains with plenty of cubical cavities where the pyrite has been leached out. Along certain joints there are stains and streaks of

iron oxide, but not nearly enough to account for the total quantity of pyrite as represented by the voids. The voids themselves are clean and white in part and at other places the leaching is not so complete. I should be inclined to guess that since the leaching on the whole has been so complete there, the precipitating agencies were not so abundant as in some of the examples that Mr. Locke has presented; in other words, silicification approached a high degree of completion. The ratio of pyrite to copper sulphide was doubtless much greater than 2 to 1.

In the workings of the Dragon Iron Mine, beneath some of these leached outcrops, iron has traveled downward and has replaced the limestone which underlies the volcanic rocks and has formed a large deposit of limonite. This iron has traveled downward a considerable distance, presumably because there were no precipitating agents to stop it until the limestone was reached, and a rough calculation of the quantity of ore that had been mined and is still lying in the ground leads to the inference that one thousand feet of these volcanic rocks must have been eroded to have furnished the necessary iron. No appreciable deposit of supergene copper has been found, and presumably should not be until the bottom of the limonite has been passed. Under these conditions downward leaching of iron took place, in contrast to these cases which Mr. Locke has presented.

Mr. Morse:[1] The next stage, I think, should be emphasized here. After we pass the ratio of two pyrite to one of chalcocite, we come into an indeterminate field as far as any evidence concerning limonite is concerned. We reach a point where there is no further indigenous limonite as a vestige, and the ore can be, of course, completely leached of iron and the iron appear as a precipitate somewhere else, provided there is a sufficient amount of sulphur to more than take out both the iron and copper of the upper disseminated zones.

It may be a matter of a little interest to mention briefly the course that this investigation took. It was not until we had experimented for a long time that we arrived at any such definite or simple statement as the one outlined. We began with the facts connected with the Tyrone and Miami ore bodies, and by chemical work in the laboratory we found that the total iron in the capping and in the ore was about the same, which somewhat surprised us because before we arrived at our conclusion, we supposed that iron was likely to be removed from the capping.

When we came to examine the neutralizing power, however, of these cappings, we found that it was greater than we had expected, even in the highly siliceous and unreactive Miami capping, and the next thing that we

[1] Introduced to the Society by Augustus Locke, as the one who did all of the chemical work connected with this paper and who devoted himself to this problem for a long time.

ran across was the fact that the quickly soluble iron in capping and ore corresponded in this way: that the capping iron soluble in five minutes in three or four per cent hydrochloric acid was in fact approximately the same as the sulphide iron content of what we regarded as typical ore vertically below the capping. The samples which are to be used for the decision as to the indigenousness of iron we found also had to be carefully selected. We could not take whipped and weathered surface material, for instance, from Miami. There the exposure to surface conditions had actually mechanically removed the limonite from cavities and the specimens that we used in determining remaining limonite were taken in part from near the surface, but were taken by removing the outside of the hand specimen or were taken from specimens drawn with ore in the mine at the time that the chute checker found that waste was coming through instead of ore. That means at a depth of 150 or 175 feet below the surface, probably closely corresponding to the complete enrichment. We knew also, of course, from the previous papers on Miami and Tyrone, and from our own analyses, that the ratio of pyrite to chalcopyrite in Miami ore was in fact about one to two, and that the ratio of pyrite to chalcocite in the Tyrone ore was in fact about two to one.

The deductions suggest that we could go to Miami or Tyrone and take surface specimens chosen below actual weathering surface zones and come close to guessing the kind of enriched ore that made that capping.

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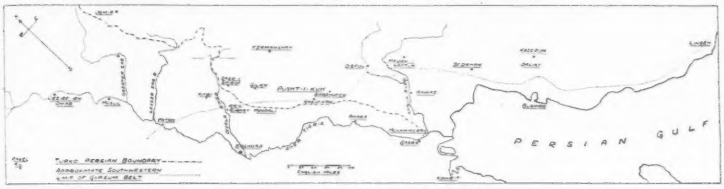
THE GYPSUM DEPOSITS OF SOUTH-WESTERN PERSIA.[1]

J. V. HARRISON.

INTRODUCTION.

ONE of the most extensive deposits of gypsum in the world extends along the eastern shores of the Persian Gulf, through the western foothills in Persia, to beyond Mosul in Mesopotamia. This belt of country is over 1000 miles long in the direction of the strike (N. W.) and, in places, is more than 50 miles wide.



SKETCH MAP ILLUSTRATING THE TREND OF THE GYPSUM BELT

FIG. 36.

To the southeast it ends near Lingeh, but to the northwest it reaches to the shores of Lake Urmiyah in Armenia,[2] (*13*, pp. 462–464) and far into Asia Minor[2] (*14*, Map 1). As early as 1855 Loftus (*11*, p. 254) had traced the gypsum bearing beds from Kazerun to Jezireh-ibn-Omar on the Tigris 90 miles northwest of Mosul, and subsequent investigators have recorded their occurrence in many other localities within the above limits, *e.g.*, De Morgan (1905), Pilgrim (1908), Stahl (1911), Busk and Mayo (1919), and Shand (1920).[3]

The present paper is an attempt to record field observations on the occurrence of gypsum in southwestern Persia, with special

[1] Published with the permission of the Anglo Persian Oil Co. Ltd.

[2] For references in parenthesis see bibliography at end of article.

[3] See bibliography.

reference to the light they throw upon the origin of the deposits of this mineral.

The thanks of the writer are due to Dr. W. R. Smellie for drawing his attention to several localities exposing phenomena connected with the present inquiry, and to Professor J. W. Gregory and Mr. B. K. N. Wyllie for helpful suggestions and advice.

VARIETIES OF GYPSUM.

A brief but excellent account of the physical properties and general modes of occurrence of gypsum is to be found in a well illustrated paper by G. I. Adams.[4] In Persia the surface outcrops of gypsum are in beds associated with marls and limestones. As beds—it occurs massive and banded, the bands varying from 2 inches to 0.1 inch in thickness but averaging 0.16 inch each; granular—the component crystals of selenite varying from 18 inches to 0.75 inch in diameter; conglomeratic or mottled—with the gypsum pebbles cemented by marly gypsum; poorly consolidated—micro-crystalline, in appearance like drifted snow; and gypsite—impure earthy gypsum within alluvium. As veins it is found as transparent selenite, as fibrous satin spar, and as opaque gypsum.

Solution is the chief factor in its weathering. The rain grooves, pits, and serrates exposed surfaces; forms swallow holes; leaves hemispherical domes on dip slopes; and produces gypsum pillars supporting protecting erratics. Solution and evaporation alternately tend to break up the other types into "snow" gypsum and the alluvium form, gypsite.

Local step faulting and local unconformities occur due to collapse of the roof following removal of the gypsum support by underground solution. Underground, anhydrite occurs below the gypsum of the surface in some places.

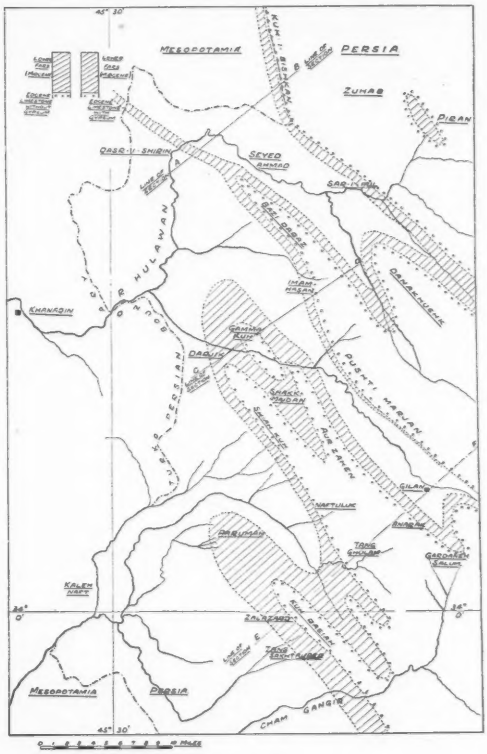
Salt outcrops on the surface in Pusht-i-Kuh, and salt springs issue from strata from Cretaceous to Plio-Pleistocene in age.

Native sulphur is found in several localities of South Kurdistan associated with selenite and limestone.

[4] I., pp. 12–14, pls. I.–IV.

AGE OF THE GYPSUM BEARING BEDS.

The lowest horizon at which gypsum has been noted in South Kurdistan and Pusht-i-Kuh is 50 feet from the top of a group of platy limestones. Immediately above them follows a thick massive limestone. Fossils occur either at the extreme bottom of this massive bed, or in the topmost beds of the platy series. Professor Gregory has kindly determined these, and he places the



SKETCH MAP
SHOWING
DISTRIBUTION OF LOWER FARS (MIOCENE)
IN SOUTH KURDISTAN

FIG. 37.

fauna as Upper Eocene (Schizaster vicinalis Ag. and Des. etc.) (*8*). In several localities the next mass of gypsum is found within the massive limestone referred to above.

In much of the area the Lower Fars assemblage of marl, limestone, and gypsum follows, apparently conformably, above this massive limestone which is regarded as Upper Eocene; but fossils from Karind collected by Loftus indicate the occurrence of beds of the Urmi Series (*15*, p. 22) underlying the Lower Fars. In Armenia a similar gypsum marl series lies unconformably upon the Urmi Beds (*13*, p. 461). At Shalil in Luristan just southeast of Pusht-i-Kuh, Dr. Pilgrim has identified beds with a similar fauna occurring immediately below the Lower Fars, the junction being unconformable. Dr. Pilgrim is inclined to regard these Urmi Beds as Burdigalian but Dr. Oswald and others place them as Helvetian, so that although the matter is controversial they belong to about the Middle Miocene (*19*, p. 45).

Overlying the Lower Fars in the Bushire region occurs the marine Middle Fars which has yielded, among other fossils, *Ostrea verleti*. Dr. Pilgrim (p. 25) interprets these beds as Middle to Upper Miocene but the similarity of the fauna to an Egyptian fauna which in recent work Dr. Hume (*10*) correlates as Plio-Miocene is strong, hence these beds may also be Plio-Miocene, a view which Professor Gregory supports. According to the more recent views, therefore, the Lower Fars gypsum-bearing beds of Persia lie between beds of Middle Miocene and Plio-Miocene age and are therefore Upper Miocene.

Gypsum also occurs with alluvium gravels and high level river terraces of recent date.

EOCENE AND ASSOCIATED GYPSUM.

A sill-like bed of gypsum, 15 to 25 feet thick, appears about 40 feet beneath the foot of the massive Upper Eocene limestone within the platy limestone series and is found over a large area southwest of Gilan and in Pusht-i-kuh. It is commonly massive rock gypsum but in places it is porous and banded, contains abundant limestone inclusions, and smells strongly of sulphuret-

ted hydrogen. Northwest of Naftuluk the same horizon is occupied by a porous, gypsum-impregnated limestone, emitting this same gas. At Anarak and in other districts where the gypsum is not represented, no peculiar band of limestone occurs at this horizon.

A large sulphur spring issues from the massive Upper Eocene limestone at the shrine of Imam Hasan. The limestone within a quarter of a mile on either side of the spring is massive and is some 300 to 400 feet in thickness. In proximity to the spring, while the selvages of the limestone remains intact, the limestone core consists of a breccia of corroded limestone fragments, cemented by calcareous gypsum. The massive limestone is traceable as an almost continuous exposure in the Pusht-i-Marjan range for more than twenty-five miles to the southeast. Throughout this length it is associated with only one other lenticle of gypsum, about 300 feet long and 30 feet thick, containing masses of gypsum-impregnated limestone, close to a fault of 1,000 feet displacement.

Across the strike 4 or 5 miles to the southwest, this same limestone outcrops in the Aur Zahen range and is exposed almost continuously from Gamma Kuh to Gardaneh Salum and beyond. In the north the limestone thins to about 100 feet, but is underlain by 200–300 feet of gypsum, before the platy limestones appear. The limestone and gypsum have an irregular junction, and the gypsum can be seen working up joint planes in the limestone, corroding it. Its surface is "worm-eaten," *i.e.,* hackly and pitted; minute canals with strings of gypsum blebs penetrate its mass; and the hammer's edge drawn across a fractured surface leaves a track of soft powdered gypsum.

Occasionally beds of gypsum were seen to end abruptly against bands of limestone-gypsum breccia passing laterally into corroded limestone, which extends along the same horizon. Elsewhere, the continuous corroded limestone bands within the gypsum are missing, and instead isolated ragged boulders of brown limestone smelling of bitumen or brown calcareous sands occur as relics of the original limestone.

A thinning of the gypsum accompanied by a thickening of the massive limestone above, and the appearance of massive limestone between the gypsum and the platy limestones below, occurs gradually in the central part of the Aur Zahen range, until at Anarak a core 100 feet thick composed mainly of limestone-gypsum breccia with about 30 feet of rock gypsum separates the two selvages of massive limestone. Less than two miles further southeast, some 50 feet of breccia remain as a core until at the distance of another mile southeast, only massive limestone 400 feet thick appears.

In the Shiah Kuh-Naftuluk and the Kuh Rasiah ranges still further southwest, the Upper Eocene limestone is of varying thickness and is underlain by gypsum. The two beds together have a thickness of about 400 feet, before the underlying platy limestones are reached.

At Tang Sakhtauber and Naftuluk the massive limestone is in beds 10 to 20 feet thick. In certain of these are numerous irregular inclusions of selenite associated with native sulphur. The selenite inclusions may be scarce or so abundant that the rock is solid gypsum with only a mesh of "worm-eaten" limestone ramifying through it. More and less affected beds are interstratified, the replacement being a definitely selective process.

Similar changes affect the Upper Eocene limestone in Pusht-i-Kuh. The upper 50 feet remain intact and massive, but below it there are 200 to 300 feet of thick corroded limestone beds. Some are predominantly gypsum with only strings of spongy limestone remaining; some a mosaic of inclusions of gypsum in limestone. Finally 50 feet of rock gypsum occur before the platy limestones are encountered. It is noteworthy that all through the district from Gamma Kuh to Kuh Rasiah, and also in Pusht-i-Kuh, sulphur bearing springs are commonly found issuing from about the horizon of the Upper Eocene massive limestone.

MIOCENE AND ASSOCIATED GYPSUM.

Overlying the Eocene limestone is the Lower Fars, which contains the thickest and most extensive development of gypsum beds in the region.

A common, but by no means absolute sequence of gypsum, green marl, and red marl, in descending order, was noted in a great number of sections in South Kurdistan and Pusht-i-Kuh.

Many of the gypsum beds gave no clue as to whether their origin was depositional or metasomatic, but the following phenomena are suggestive:

At Tang Sakhtauber are occasional alternations of thin limestone foliæ with banded gypsum. The banded gypsum itself contains lenticles of green argillaceous limestone, and thin bands of calcareous gypsum. The thicker limestones show a tendency to become corroded along definite bedding planes.

Some of the limestones that occur near here, at Zalazard, Tang Ghulam and Shakmaidan, contain gypsum blebs; in certain places the amount of gypsum to the limestone is small, but in others the proportion is large. At Nasiriyan in Pusht-i-Kuh a bed was exposed where the gypsum inclusions are of greater bulk than the perimorphic limestone which shows advanced symptoms of corrosion.

The lowest five hundred feet of the Lower Fars in South Kurdistan is predominantly gypsum, but some thin corroded limestones can be traced in these beds. They are "worm-eaten," veined by gypsum, and lie against the gypsum with an irregular pitted junction.

The variation in limestone content from place to place in the Lower Fars is noticeable. Fossiliferous, unfossiliferous, oölitic, and close even grained limestones all occur.

An abnormal sequence lies upon the Upper Eocene limestone at Piran, north of Sar-i-Pul, where marls, thin sandstones, and limestones rest directly on the thick unaltered limestone and contain very little gypsum.

RECENT GYPSUM.

Gypsite occurs at several places in the Mesopotamian alluvium. This spongy earthy gypsum is the result of evaporation of subsoil waters in the summer, and forms beds a few feet thick just 1,500 feet above sea level, overlying a mound of alluvium and beneath the surface. Similar material was noted near Naftuluk, calcareous gravel.

Within the waters welling from a warm sulphur spring at Bardhofen in Pusht-i-Kuh, pebbles and boulders of limestone from the gravels of the plain were found coated with gypsum, below which was left a pitted, corroded surface of limestone. The course of streams flowing from this and neighbouring springs is marked on the plain by surface deposits of spongy gypsum traversed by inconstant, irregular, but almost horizontal veins of thin brown porous limestone. These deposits end abruptly on either side against thick beds of limestone gravel, up to 40 feet thick. It is certain that the spring waters are quite insufficient in velocity and volume to have removed the gravels that lay in their course mechanically, so that the local beds of gypsum exposed to a thickness of twenty feet can have been formed only by the chemical replacement of the carbonate of the limestone by the sulphate of the gypsum, a process which was witnessed in the springs themselves as mentioned above.

MATHEMATICAL CONSIDERATIONS.

Since 0.126 per cent. of calcium sulphate occurs in normal sea water, the total evaporation of 2,260 cubic feet would be required to yield one cubic foot of anhydrite provided all the calcium sulphate were to crystallize as anhydrite, but if it were to crystallize as gypsum it would require the evaporation of 1835 cubic feet. But common salt commences to crystallize in sea water concentrated to one tenth of its original volume (*9*, p. 98). The amount of anhydrite deposited up to this point is approximately 1 cubic foot per 2,600 cubic feet of original sea water, or of gypsum 1 per 2,100.

The Lower Fars extends over an area of about 50,000 square miles and single beds have been noted up to 50 feet thick. For such a bed to be produced by a sea which was not augmented in saliferous content from without, a depth of 20 miles would have to be evaporated to one-tenth its bulk. Or were it deposited in a lagoon 500 feet deep which was periodically sealed off and then refilled, four refillings would be required for each foot of gypsum, *i.e.*, 200 cycles for one such bed.

If the banding prominent in some of the beds were the result of seasonal variation causing deposition in summer with refilling in winter, a lagoon 30 feet deep would be sufficient to produce a band 1/6 inch thick. The same deposition would ensue in a basin 100 feet deep if evaporation were carried to half bulk.

Banding could also be produced by seasonal variation in the rate of evaporation in a lagoon replenished over a bar in the manner suggested by Ochsenius (quoted by Clarke, *4*, p. 215) but the area of the Fars sea was so enormous that it is difficult to conceive of such suitable conditions.

To produce the gypsum deposits of the Lower Fars between Jezireh-ibn-Omar and Lingeh (1,000 miles by 50 miles by 700 ft.) *i.e.*, 7,000 cubic miles, a sea 14,000,000 square miles in extent and 1 mile deep would have suffered evaporation to one-tenth bulk. This means that such a sea as the Indian Ocean, bounded by Antarctica on the south, Africa on the west, Asia on the north and Australia on the east, would have had to supply water to a depth of one mile from its surface.

When it is considered also that the gypsum deposits of the north of Mesopotamia, the Red Sea, and the Carpathians, are associated with beds of about the same age it would mean that a colossal volume of water would have had to be evaporated.

COMPARISON OF PERSIAN AND EGYPTIAN GYPSUM BEARING FORMATIONS.

The Egyptian deposits of gypsum and associated strata have been described by Dr. Hume (*10*). Reasons have been given above for regarding the main gypsum bearing strata of Persia

and Egypt as being of the same age. In both regions minor gypsum bearing beds of other ages have been noted. Both vary in the proportion of limestone to gypsum within the Upper Miocene, e.g., Dr. Hume states (pp. 23–25) that in the Plio-Miocene between Gebel Gharib and Ras Shukhair gypseous limestone without massive gypsum occurs, though further south a typical gypsum area appears in the center of these strata. Both contain limestone deeply affected by gypsum, for in Egypt casts of bivalves entirely replaced by selenite are found—"evidence that the gypsum is at least in part an alternation from carbonate of lime" (p. 25). In each, a series of thick gypsum beds is interstratified with marls and thin limestones. The occurrence among the gypsum beds in Egypt of corroded beds of "dolomitic limestone" which vary rapidly in thickness has been commented on by Dr. Hume (p. 82).[5] Strikingly similar are the very lenticular "pumice like or vesicular limestones" exhibiting "what may best be described as flow structure" occurring at Maidan-i-Naftun, described by Mr. S. L. James in his contribution to the discussion on the paper by Busk and Mayo[6] (pp. 26–28). Tufa-like beds of limestone, ropy in structure, occurring in beds up to 25 feet thick have been seen by the writer at horizons in the Lower Fars. Only a few hundred yards away, no limestone occurs more than 2 feet in thickness and it is of normal type. It was noted that the porous limestone occurs only where faulting or some other disturbance had taken place, and is always associated with gas bearing springs.

Somewhat allied in appearance to, but on a smaller scale than these tufa-like limestones, are the corroded, porous limestones found in the recent gypsum beds at Bardhofen, where the calcareous gravel has been altered by the sulphur bearing streams. All this evidence lends weight to the deduction of Dr. Hume (p.

[5] "The type specimen of the porous dolomites taken for analysis did not contain magnesia" (Hume, p. 63).

[6] See also Craig, p. 48. It should be recorded that no detrital limestone, *i.e.*, in the sense of a calcareous grit or breccia, was observed in the Fars of South Kurdistan or Pusht-i-Kuh, the only detritus being fragments of shells of fauna which lived and died close to the bed in which they now occur.

44) that the porous limestones "are in part due to the effects of solution" and redeposition of calcareous material and may "often be of later date than the gypsum itself."

The samples of anhydrite and gypsum obtained from bore holes are seldom calcareous; therefore the gypsum beds can not be invoked to supply the calcium carbonate, as in Egypt. But with circulating waters rich in gases the thick limestones below would readily yield this material, which would tend to be deposited in fissures near the surface.

ORIGIN OF THE PERSIAN GYPSUM.

Dr. Pilgrim (*15*, p. 33) states that he regards the gypsum of the Fars as produced by the action of sulphurous fumes reacting with carbonate of lime in water, resulting in the deposition of sulphate of lime as gypsum. He does not accept the idea that the gypsum was due to the evaporation of sea-water. "In an open sea of such extent as we know the Lower Miocene seas of Fars times to have covered it seems impossible that such concentration could have occurred."

Mr. Cunningham Craig disagrees with this theory and champions a view involving desiccation in basins. (*2*, pp. 32–33.) This corresponds to the "working hypothesis" given by Dr. Hume (*10*, pp. 34–39) to account for the origin of the Egyptian gypsum, *i.e.*, evaporation in lagoons depositing salt and gypsum, with discharging streams supplying the sediment to form clay layers.

Dr. Stuart (*18*, p. 67) after ably marshalling the facts available regarding the gypsum deposits of the Salt Range in India, concludes by saying that "it has been formed . . . by the reaction of sulphuric acid set free by the decomposition of sulphide of iron in the salt on adjacent calcareous material."

In Persia, the platy siliceous limestone underlying the massive Upper Eocene limestone contains nodules of pyrites wherever it is eroded in South Kurdistan or Pusht-i-Kuh. From the Cretaceous mudstones below them small sulphur and occasional brine springs emanate. The source of reagents required for the meta-

somatic replacement of limestone is therefore present within the underlying formations.

Calcareous gravels may be observed changing to gypsum under such action at the present day. The Upper Eocene limestone is found massive where it is free from sulphur springs, but if a sulphur spring issues from it, it is found with an affected core. It has been traced along a continuous outcrop through gradual stages from limestone to gypsum. It has been found in beds showing the insidious inroads of the gypsum in the increasing porosity and volume of gypsum blebs and inclusions. Frayed residual limestone bands have been found where this action has been long continued, until occasional "worm-eaten" boulders of limestone or patches of calcareous sand are all that remain. For the origin of the gypsum within the Eocene limestone the case is complete, and points to metasomatic replacement of the limestone.

The sill-like gypsum within the platy limestone occurs between unaffected beds. It sometimes contains limestone fragments, and is associated with porous limestones smelling strongly of hydrogen sulphide. It has been observed passing laterally from a band of massive gypsum to a bed of limestone gypsum breccia. Therefore it also appears to be other than sedimentary in origin and due to chemical changes wrought in the limestone.

In the Lower Fars limestone, bands have been observed containing blebs of gypsum. Gypsum beds have been found containing angular fragments of argillaceous limestones, and elsewhere are traversed by thin deeply corroded limestone bands. Bedded gypsum has been observed in the process of formation from bedded limestones, and conglomeratic gypsum from limestones rich in gypsum inclusions. There is conclusive evidence therefore that some of the Lower Fars gypsum has been produced by the replacement of limestone bands.

Besides the huge volume of sea water which would have been required to produce the Fars gypsum, there would have been others required at the same time in northern Mesopotamia, Asia Minor, and Egypt, which makes the conception of evaporation of

sea water as the producing factor still more difficult. It is therefore necessary, to find some source of the calcium sulphate other than normal sea water. But as some of the Fars gypsum is certainly due to deposition from solution, a modification of Hume's "working hypothesis" seems applicable here, discharging streams supplying both sediments for the clays and solutions for evaporation.

The reason for the greater resistant qualities of some limestones can only be determined by exhaustive chemical analysis, but it is evident from field work alone that high argillaceous content tends to confer immunity to attack. Within the platy limestones a fault fissure cutting through these beds was found filled by gypsum smelling of sulphuretted hydrogen, while the limestones on either side were quite unaltered. That some beds in the massive limestone are more easily altered than others is at once apparent from the alternations of beds rich and poor in gypsum inclusions, and it is confidently expected that a series of analyses would discover the impurity which acts as the catalyst.

THE AGE OF THE GYPSUM.

After the close of the Lower Fars period, sediments continued to accumulate and cover the underlying beds. As the overmantle thickened and folding was initiated, sulphur-bearing solutions generated in the underlying mudstones commenced their attack under favorable conditions, the earth movements serving to circulate supplies of the reagent.

Much of the gypsum in the Upper Eocene must have been formed before the end of the orogenic movements, for in some regions where the limestone is largely replaced by gypsum, complicated corrugations are superimposed upon the major structures which are simple where the limestone is massive. But as limestones belonging to both the Eocene and Miocene ages were observed in which only partial change into gypsum occurs, and as the limestone pebble banks of recent date are still undergoing metamorphism into gypsum, there is evidence that the processes

are still active. It is probable that the changing of the limestone into gypsum started in the Pliocene and continues today.

SUMMARY.

1. On the surface gypsum is exposed in beds in several habits. Below it is partly represented by anhydrite. Solution is the chief factor in weathering. Native sulphur and rock salt are associated minerals.

2. Bedded gypsum is associated in places with beds of Upper Eocene, Upper Miocene, and Recent age, in a belt of country more than 1,000 miles long and 50 miles broad.

3. The change from gypsum into massive limestone occurs within comparatively short distances, and limestone in various stages of corrosion by gypsum is found in both Eocene and Miocene beds.

4. Recent limestone gravels occur in process of replacement to gypsum, where acted on by sulphur bearing streams.

5. For the deposition of the Lower Fars gypsum alone, 14,000,000 cubic miles of sea water would have been required to undergo evaporation to 1/10 bulk, and other vast volumes of sea water must be postulated as evaporating at about the same time in Egypt, Asia Minor, and Europe if the gypsum be regarded as a deposit from evaporating seas.

6. The main gypsum-bearing beds of Egypt and Persia are similar in age and in many other characteristics. Proof is available that both have been produced in part by chemical replacements of limestone.

7. The porous variable limestones of Persia are regarded as deposited from solutions subsequent to the gypsum in which they occur.

8. The gypsum occurring with the Eocene limestone is regarded as due entirely to the metamorphic action of sulphur-bearing solutions from the mudstones upon the limestones.

9. Some of the Fars gypsum owes its origin to a similar chemical action on the limestones of that formation and some to deposition from evaporating solutions.

10. The metasomatic gypsum has been forming since Pliocene times and continues to form at the present day.

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GLASGOW, SCOTLAND.

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ORE DEPOSITION AT THE CREIGHTON NICKEL MINE, SUDBURY, ONTARIO.

J. E. SPURR.

THE occurrence in the Creighton mine of a pegmatite veindike carrying chalcopyrite and pyrrhotite among its constituent minerals is, as far as I know, something not hitherto observed, and therefore one which deserves to be recorded. The occurrence was in the roof of a working stope on the 18th level (1800 feet on dip of ore) and the veindike was a foot or so wide, with a central crystallization of sulphides the size of a hand. The specimen which I was fortunate enough to secure, however, showed the veindike only about three inches wide, and with a central

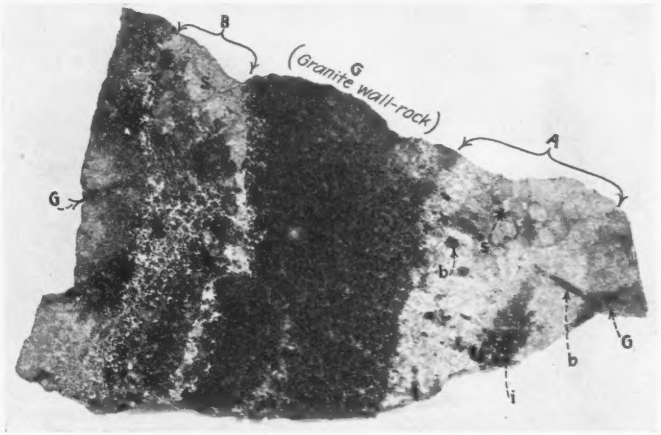

FIG. 38. Photograph (2/3 natural size) of specimen from stopes in the 18th level of the Creighton mine, Sudbury, Ontario. Shows sulphide-bearing pegmatite veindikes (*A* and *B*) in dark granite wall rock (*G*). *s* = sulphides. *b* = biotite. *i* = inclusion of granite in the pegmatite veindike (*A*).

crystallization of copper pyrite (with quartz and biotite) an inch or so across. When the specimen was sliced, giving the face shown in Fig. 38, the amount of sulphides was still less. Nevertheless, the import is quite as clear. The pegmatite (*A*) is an intergrowth of quartz and pink feldspar, of moderate fairly even texture, that is to say, with the average diameter of the crystals, say 1/8 to 1/4 inch, which is very much coarser than the average grain of the dark granite wall rock. Some biotite (*b*) lies in this quartz-feldspar aggregate, in tabular crystals up to 1/2 inch long, but generally much shorter. The biotite is, however, clustered more in the center of the veindike, where the sulphide (copper pyrite) is distinctly segregated (*s*), and where it is closely associated not only with biotite but with quartz,—but not so closely with feldspar. The crystallization periods of all these veindike materials, then, overlap; but the feldspar is relatively the earliest and the sulphide crystallization the latest—in the sense that the sulphide crystallization outlasted that of the quartz and biotite, with which it is also in part strictly contemporaneous. In the whole veindike the minerals tend to assume the idiomorphic or euhedral form—*i.e.,* to develop their individual crystal outlines, so far as possible—giving a stage between the pegmatitic (graphic) and aplitic (panidiomorphic) texture. The biotite intercrystallized with the sulphides is in little hexagonal tablets.

The other vein (*B*) shown in the specimen appears in the mine (and when casually examined in the hand specimen) to be a pure sulphide veinlet, of the same chalcopyrite (*S*) as that shown in the neighboring pegmatite veindikelet, and with a very little pyrrhotite also. But examination of the polished face shows that this sulphide veinlet, besides the sulphides, has also much quartz and pink feldspar, and indeed much biotite; so that it falls into the same type of vein or veindike as the other; only the sulphide, quite subordinate in the one shown on the right, is quite predominant in the other. In the sulphide veinlet there are many small crystals of biotite and quartz embedded in the masses of chalcopyrite. On the other hand, the crystallization of the chalcopyrite in general outlasted that of the associated minerals,

and tiny fissure veinlets of the sulphide cut the older and larger of the quartz crystals. These earlier and larger quartz crystals, and the associated feldspar crystals, are of much the same dimensions as those in the predominantly quartz-feldspar veindike.

These pegmatitic veindikelets were rare and unusual variants of the mass of ore veins reticulating the roof of the stope where they were found: the ore veins in general were of the massive sulphide, without noticeable gangue, so characteristic of the ore in the Creighton mine and the other nickel-copper mines of the Sudbury district.

The genesis of the sulphide veins and larger injections in the mine is thus indicated: this specimen almost by itself furnishes what appears to be a reliable key. The ores have originated through magmation: not directly from the norite or granite or any of the other rocks exposed, but from a deeper source—the same general source whence the norite, granite, and other emanations were derived. The ore veins (veindikes) pierce the older rocks, whether norite or granite or the Keewatin rocks into which both were intrusive—first the norite and later the granite. Some of the magmatic emanations, in turn, were later than the ore intrusion—such as the diabase, pointed out by Knight and others. The process of magmation was that which I have outlined for (on the average) basic magmas in my book on "Ore Magmas," [1] a process analogous to that which takes place in more siliceous magmas but which results in an ore magma containing relatively little silica and gaseous constituents, including water. Hence the characteristic pegmatitic minerals, such as quartz, feldspar and biotite, are greatly subordinate in amount at Sudbury; whereas in the case of the ore magma differentiated from an overwhelmingly siliceous magma, the pegmatitic minerals, especially quartz, are enormously preponderant—such as in the case of the gold-quartz veins of Porcupine, for example.

The borders of the veindikelets shown in the figure, though clear cut, are "frozen," by crystallization, to the wall rock. An item of interest in the predominantly quartz-feldspar veindike, is

[1] Vol. II., pp. 589, 597.

the isolated and suspended inclusion of the dark granite wall rock (*i*). This shows considerable evidence of attack, along its borders, by the pegmatitic ore-magma.

An examination of the specimen microscopically has been made for me by Dr. F. S. Wright, who determined the wall rock as biotite hornblende granite. The feldspar of the granite is chiefly microcline with some albite. The dark colored minerals—biotite and hornblende—constitute from one third to one half the volume of the rock. The feldspar of the pegmatite corresponds with that of the granite—chiefly pink microcline, with an occasional grain of albite-oligoclase. "The quartz and biotite show the same characteristics as the quartz and biotite of the granite." The chalcopyrite appears remarkably pure: it contains many crystals of biotite and quartz grains; "also small threads of a yellow mineral with a decided pinkish cast and metallic luster—probably another sulphide." Quartz veinlets cut and are later than the chalcopyrite. Dr. Wright remarks:

> It appears to me that chalcopyrite was deposited from the pegmatite solutions as a late phase to crystallize out; also that the pegmatite veins are essentially from the same source as the enclosing granite. The pegmatites were of course later than the granite and the conditions of their crystallization somewhat different, as is evident from the pink color of the pegmatite microcline.

Elsewhere in the mine I observed other veindikes of similar pegmatite, but consisting mainly of quartz and feldspar,—with sulphides, such as chalcopyrite, reticulated through them, and thus more plainly a later crystallization than in the key-occurrence above described. As I observed in my notes at the mine, all this indicates "a crystallization of ores from a highly sulphidic magma, from which a little quartz, feldspar, and biotite first crystallized, the sulphide being last. The pink feldspar of the pegmatite suggests a relation to the granites, which also have pink feldspar."

In general the ores of the mine, of which the above examples are details, are almost exclusively sulphides, and form sharply intrusive veindikes of all sizes, containing characteristically clean-

cut, angular, fragments of the wall rock, quite isolated and floating free. These veindikes show no particular preference for any of the various wall rocks. Besides the norite, there are two bodies of granite—coarse and fine respectively—occupying distinct areas in the mine, both of which are cut by the ore. According to Mr. Brock, the mine geologist, a norite dike, which distinctly cuts the main norite, is itself cut by ore. While the main ore body lay at the contact of norite and granite in the upper levels, the downward pitch of the ore continued uniform, while that of the contact flattened, so that the main orebody passed downward into granite on both walls.

The small item above described adds to the accumulating weight of evidence previously recorded, which, all together, put quite a different aspect on the Sudbury ores from the view originally presented—that the ores were magmatic differentiates in place, and had settled as earlier formed sulphides to the base of the molten norite sheet through the influence of gravity. Later work showed, however, that the general sequence at the Creighton mine (as given by Knight) was (1) Keewatin greenstone; (2) norite intrusion; (3) granite intrusion; (4) ore injection; (5) trap dikes; (6) olivene diabase dikes. The significance of this sequence is heightened by the pegmatitic variant of the ore which I have recorded above, and which shows that the ore has a closer relation to the granite than to the norite. Nevertheless, it is evident that all the intrusives, from norite to olivene-diabase, are emissions from a single underlying magma reservoir, and the relative proportion of the different intrusives shows that the reservoir was of an average relatively basic composition, as was typical of the Keewenawan magmas. The granite was a differentiate from this underlying parent magma; and the ore intrusive represents a highly specialized magma, likewise derived from the underlying reservoir, and representing an independent member in the series of magmatic injections.

I have to thank Dr. E. S. Moore, of the University of Toronto, who was present (as was Dr. A. C. Cleland, of Williams College) when the pegmatite was detected in the mine, for having the specimen sliced and polished at the University.

It is of interest also to record changes in the relative copper and metal content of the Creighton ore with increasing depth, called to my attention both by Mr. Brock, the geologist at the Creighton mine, and by Dr. Miller, Provincial Geologist, Ontario Bureau of Mines. The nickel content increases with depth. While the upper orebody averages about twice as much copper as nickel, the lower orebody has the two metals in about equal proportions. But this difference is probably not to be referred to difference in the orebodies, for the change to increasing nickel took place in the lower part of the upper orebody. The lowest level is about 2000 ft. deep, on the dip of the ore—more than half that much vertically, the ore dipping about 45 deg. The change probably represents the variation of ore deposition according to the Zonal Theory. In the basic magma sequence, the copper zone ideally overlies the nickel zone.[2]

In this connection with the Zonal Theory, I noted in the geological map of the Sudbury district, galena veins mapped in two places, in the center of the Sudbury syncline, at a much higher geological horizon than the nickel ores that occur on the margin of the syncline. And in one mine at least the nickel zone and the galena zone have been brought together by superimposition with falling temperature. This is the Worthington mine, where the stages of geological history were:[3] (1) Sedimentary rocks of Temiskaming series. (2) Diorite (now greenstone) intrusion. (3) Norite dike. (4) Injection of nickel-copper sulphides (proportion 4 of copper to 3 of nickel). (5) Trap dikes. (6) Diabase dikes. (7) Veins of zinc blende, galena, pyrite, and calcite.

[2] "The Ore Magmas," Vol. II., p. 611.

[3] Report Ontario Nickel Commission, 1917, pp. 174–179.

New York City.

EDITORIAL

REPLACEMENT AND FOLDING.

It is well known that the intrusion of igneous rocks is more or less intimately connected with tectonic disturbances of the intruded formations, and the idea is largely accepted and gaining further ground that intrusion and folding or fracturing are the effects of common causes. This is particularly clear when the deeper zones are considered, where folding has predominated almost or entirely to the exclusion of fracturing. It is also an established fact that very often the development of replacement ore deposits has accompanied igneous intrusion. However, the examples studied do in the vast majority of cases represent the zone of fracture. Comparatively little attention has been given to the possibilities of similar reactions in connection with intrusions in zones of dominant flowage, in the course of a folding epoch, and but little work has been done to ascertain the influence of the conditions of folding on the replacement process. Several observers have noted and interpreted such features, particularly in the relation between the shape of ore bodies and the structure of the enclosing folded rocks, but there is still a lack of observational evidence that is keenly realized if one, struggling with these problems, turns to the literature on ore deposits to obtain further light on the subject.

It is probably significant that the importance of the problems in question has been fully realized only by those who study the deep sections of the Archaean. In several papers in this journal, Dr. E. C. Andrews has pointed out that such conditions have reigned in the Archaean of the southeastern portions of the Australian continent, where the Broken Hill lode forms an excellent example. The present writer's attention was turned to the same problems when studying certain ore deposits of the Swedish

Archaean. About some of them—several forms of sulphide ores—a brief summary has already been given in this journal (1921, p. 279). Since then, also magnetite deposits of the same type have been described, from Riddarhyttan in Central Sweden. The experience derived from these studies seems to supplement Dr. Andrews' Australian evidence in several respects, by illustrating other variations, and these pages are written in the hope that they may help to stimulate the study of these particular problems. It is hoped that attention to the features and the possible explanations outlined here will not only contribute something to our knowledge of metamorphism and rock deformation, but also be of use in the exploration and development of such ores.

The Swedish deposits in question occur in altered rocks that have had the character of fine-grained crystalline schists made up mainly of feldspar and quartz (leptites). The associated replacement deposits in limestone do not in any way, either in mineral composition or in texture, differ from those of the zone of fracture. Neither do they show any appreciable influence of the structural attitude of the containing limestone bodies. They are, therefore, not further considered here. The whole formation exhibits an intense isoclinal folding, with very strong cross-folding that has resulted in a generally steep pitch. Schistosity by crystallization is practically parallel to the bedding.

The characters that originally led the writer to regard the deposits in question as formed *during* an epoch of folding were the following. The mineral aggregates that were formed by replacement exhibit schistosity by crystallization and often also a very pronounced banding, and further, although the ore bodies themselves show the influence of folding, it appears that the formation enclosing them had been folded, probably along similar lines, before replacement started. The latter features the ore bodies share with the dominantly granitic intrusions of the folding period. These are apparently intruded in connection with the folding, but there are signs indicating that the folding went on until the gradual solidifying of the intrusives made the complex too rigid. Naturally the igneous masses, when once solid, could

not be much deformed, therefore their shape is not appreciably influenced by later folding. These similar relations to the folding form one of the chief reasons for regarding the deposition of the ores in question as genetically connected with the intrusions.

The special characteristics of replacement in silicate rocks under conditions of folding may be referred to three groups, according to the determining factors, which are, (1) the depth necessary for plastic deformation (entirely or in part), (2) unequal pressure (stress), and (3) the structure of the enclosing rocks. The first factor influences the kinds of minerals forming, the stress determines the texture of the metasomatic aggregate, to some extent also the shape of the deposit, and probably the mineral composition, while the structure may have a double influence on the shape, in the combination of pre-mineral and post-mineral folding.

In the deposits now considered, the ***mineral composition*** is characterized by the presence of dominantly anhydrous silicates of alumina, magnesia, and iron, as andalusite, cordierite, anthophyllite, alamandite. Their appearance may be due to the high temperature probably reigning in the zone of flowage and intrusion, but it is also of interest to note, as recently pointed out by N. Sundius [1] that it means a change to higher specific gravities, and forms in replacement a counterpart to the volume law in ordinary recrystallization.

In *texture,* the salient feature is an often well-marked schistosity by crystallization in the aggregates of new-formed minerals, entirely conforming to the schistosity of those associated rocks that were recrystallized without any change in composition. It is not unusual to find cordierite and andalusite developed along certain schistosity planes, as crystals several decimeters in length but only a couple of millimeters in thickness. Also the beautiful "stars" or "suns" of orthorhombic amphiboles are generally developed parallel to the schistosity. Several facts indicate that these minerals were the original products of the metasomatic action. Their shape may therefore be interpreted as showing that

[1] *Geol. Fören. i Stockholm Förh.*, 45, 1923, p. 361.

replacement took place under a marked lateral pressure (stress). Equally important is the sometimes well-marked *banding* in the replacement rocks. The structural control of replacement makes a comparison with the unaltered rock difficult, but one obtains the impression that the metasomatic products are quite as distinctly banded as the original rocks, and perhaps even better. It is known that even rather slight differences in the composition of strata may give rise to more conspicuous differences in the replacement products. Yet it is probable that the preservation of banding just considered is due largely to the directing force apparent already in the shape of the mineral grains.

On a larger scale, similar features appear in the relations of the ore bodies as such to the *structure* of the enclosing rocks, in that the ores are generally parallel to the bedding and schistosity directions of the latter. Therefore, the replacement bodies appear as interstratified in the formation containing them, and it is often only with difficulty that their true nature is discovered. Cross-cutting relations are very unusual, and even vein-like aggregates, when rarely found, are parallel to the structure of the country rock.

The study of the relations between the ore bodies and the structural elements of the enclosing rocks is complicated by the fact that one has to reckon also with distinctly post-mineral folding, but the following points are discerned. It appears as if replacement sometimes took place along certain pronouncedly schistose layers in the steeply inclined formations in very much the same way as along a fissured zone, only with the differences determined by stress. It is obviously difficult to tell such zones from those of mineralized faults along the axial plane of folds, which may have occurred where there was some fracturing combined with the plastic yielding. Again there are examples that both anticlinal and synclinal forms have controlled the development of replacement deposits. The reasons for this may be several, as differences in composition and texture in the various strata. The ore bodies follow the pitch of the folds, often in a very marked manner, just as the linear schistosity not only of the

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bedded rocks, but also of the intrusives, follow the same direction. The pitch length may then be the longest dimension of the ore. An ore body with a low pitch can soon give out when followed along the dip, thus a deposit of this character, although of deep-seated origin, may be of a rather limited extent vertically. (Compare Broken Hill.) On the other hand, if the pitch is steep, the ore may show a remarkable persistence in depth. It is probable that replacement is rarely localized to synclinal basins except in steeply pitching folds.

Somewhat analogous shapes are known also from ores that were formed before any folding occurred, as the stratified iron ores intercalated in the same formation that carries the replacement ore deposits of Central Sweden. The thicker portions determined by "similar" folding show the same relations to the pitch as do the replacement bodies, but it is not necessary that the longer axis of each ore body should be in the direction of the pitch. This happens, however, if "similar" folding goes so far as to destroy the unity of the ore body. Then each portion has its longest axis in the pitch direction, as have the replacement bodies referred to. Thus there are analogies, due to the same controlling structural forces, but also differences, due to different origin and therefore different age in relation to the folding.

PER GEIJER.

DJURSHOLM,
SWEDEN.

DISCUSSION AND INFORMAL COMMUNICATIONS

FORCE OF CRYSTALLIZATION AT BENDIGO.

Sir: F. L. Stillwell's article entitled "A Bendigo Problem and its Bearing on the Force of Crystallization," published in the August, 1923, issue of ECONOMIC GEOLOGY, is a very instructive study but the phenomenon described seems susceptible to another explanation than the one given; as follows:

The fault through *P* (see the Fig. 69) and the fault through *Q* were originally of pre-mineral age, formed no doubt contemporaneously with or following the folding of the strata. This is the stage of folding, fracturing, faulting and adjusting movements along bedding planes mentioned by the author near the top of page 509. Ore deposition followed along the beds and faults. Then a recurrence of adjusting movements took place, referable to a continuation of the same forces, such as lateral earth pressure, originally responsible for the folding, fracturing and faulting of the formations. These post-mineral movements polished and slickensided the quartz at *P* and *Q* as described by the author.

Recurrent earth movements are common phenomena in geologic history and when rocks have been deeply buried and especially when they have been in zones of disturbance they are apt to show evidences of repeated differential movement. If orebodies happen to be present in that particular locus of the earth's crust they too will be affected. A plane or zone of weakness once established characteristically persists as a locus of recurrent movement. In the Porcupine district of northern Ontario, Canada, I have noted evidences of at least three recurrent movements along a fault, as shown by three sets of parallel striations, each set making a small angle with the others, on quartz of the

truncated lode. Familiar examples of recurrent movement are to be found in many regions in the shearing, slickensiding and polishing of lodes along their walls. These walls were obviously pre-mineral planes of dislocation, inasmuch as they control the disposition of the vein, but they have become post-mineral planes of movement as shown by the shearing of the vein material. Lodes may be opened and new material deposited. These conditions may occur over large areas and can frequently be linked with regional deformation. Force of crystallization may be a factor in these movements but it is inconceivable that crystal growth along certain restricted loci can explain them.

What is there about the Bendigo problem that makes it necessary to invoke the force of crystallization, between the beds, to explain the slickensiding at *P* and *Q*, rather than post-mineral movement due to external earth stresses? Mr. Stillwell emphasizes the slickensiding at *P* and *Q* and while he does not specifically state so, it may be presumed that this slickensiding is confined to the vicinity of *P* and *Q* and is not found at other places along the faults. If this is true perhaps it favors the author's theory but it is by no means conclusive. Earth forces transmitted through the earth's crust are extremely variable in their effects. Not only is the magnitude of the forces subject to wide variation but relative resistance to differential movement produces many complex and variable effects. On any single fault evidences of movement may fluctuate widely, depending, among other things, upon variable forces, preëxistent planes of weakness and the physical character of the intersected rocks. Hence it is perfectly conceivable that the quartz should show maximum slickensiding at *P* and *Q*, with or without appreciable evidence of movement at other places along the faults.

Nevertheless it would be expected that the Bendigo deposits should characteristically show evidences of post-mineral movement, if such occurrences as at *P* and *Q* have resulted from extraneous earth stresses. If strictly localized by such conditions as those described it is very interesting evidence and I would like to hear further from the author on this point. It would also be

useful, in order to more fully gauge the merit of the author's theory, to have him describe the effects of mineral growth at *A*, *B* and *C*, where this growth has been at a maximum.

ELLSWORTH Y. DOUGHERTY.

HEROULT, CALIF.

SEDIMENTARY PHASES OF ADIRONDACK MAGNETITES.[1]

Sir: I have been deeply interested in the discussion of my paper bearing the above title, by Miller, Newland, and the editorial by Leith. There is one point which appears to me to be over-emphasized by both Miller and Newland. I certainly am not wholly committed to the sedimentary theory of the origin of either the gray gneisses or of their contained magnetites. Even if the gray gneisses are finally decided to be sedimentary, it does not at all follow that the magnetites have the same origin. I have only emphasized the sedimentary phases of these rocks and their nontitaniferous magnetites. Naturally I have laid stress on field studies of relations and have placed petrographical and laboratory results in a subordinate position.

Derivation or Origin of the Gray Gneisses.—Miller, Newland and Kemp appear to regard these rocks as having been derived either from the gabbros or the syenites. My own field work, and rock and ore study suggest that if the gray gneisses are derivatives the ordinary granites are their origin.

Roesler in the "Iron Ore Resources of Europe" (p. 10) states:

> Two types of deposits of this class of ore are of common occurrence—deposits associated with gabbros and deposits associated with granitic rocks. The ores associated with gabbros carry iron mainly as magnetite and most of them contain considerable titanium which occurs as ilmenite. . . . They are regarded as segregations within the igneous magma. The ores associated with granitic rocks contain magnetite as their only iron mineral. . . . If they contain titanium it occurs as titanite, not as ilmenite.

[1] ECON. GEOL., vol. XVII, pp. 633–654.

The above is practically identical with my personal observations in the magnetic iron ore fields of New Jersey and New York. There is, however, one point on which, if I understand Roesler correctly, I am not ready to accept "common granites" (feldspar-quartz-muscovite) and gneisses or granitoid gneisses or gneissoid granites as necessarily igneous. My main objection to this lies in the quartz constituent of these rocks.

Sulphur Associated with Magnetites in White Lime.—Miller, quoting from Newland, on the above, states:

> The fact that considerable quantities of sulphur or pyrite almost never fail to be present in those nontitaniferous magnetites which are directly associated with undoubted Grenville strata in various parts of the Adirondacks, while little or no pyrite occurs in the ores associated with the undoubted syenite-granite series.

I am at a loss to understand exactly to what kind of rocks Miller refers to as "undoubted syenite-granite series." If he means the well recognized gabbros, the statement as to sulphur will not hold good for pyrite is a common mineral in both the gabbros and the titaniferous ores in them. Specifically, the Moose Mountain deposit, near Hammondville, has upwards of two per cent. It is even present in the large deposits at Lake Sanford. If he means the inclusion of the gray gneiss rocks, I cite the sulphur contents of the ores of four large mines near Crown Point: The Gunnison with Fe–44 per cent.; S–1.96 per cent.; Breed mine, Fe–50 per cent.; S–1.98 per cent.; Vineyard, Fe–44 per cent.; S–1.98 per cent.

The Saxe ore bed, also near Crown Point, Grenville, has Fe–53 per cent.; no sulphur. In the appendix is a list of New Jersey iron mines in the white limestone series in which it is shown that out of seventeen mines in these rocks, only three have sulphur above the commercial limit. The average will run about 0.5 per cent.

From Bayley's Iron Ores of New Jersey, thirty-seven mines opened in the gray gneiss rocks carry sulphur; minimum is 0.27 per cent.; maximum, 34 per cent. The general average is about 3.29 per cent. Of the six main producing magnetite mines, one

large producer has upwards of 1.68 per cent. and the ore has to be roasted before it can be used; the five have practically no sulphur or only traces. One formerly large producing mine, the Hacklebarney, averaged 3.3 per cent. S. Many non-operating mines have magnetite and pyrite in about equal amounts—about 23 per cent. S. A complete list of the two classes of deposits would show sulphur quite as abundant in the gneisses as in the White Limestones.

So far as I am concerned, there are only two rocks of the Grenville that I am just as sure of as I am of the typical gabbro, anorthosite, and syenite. These two are the graphitic white limestones and the accompanying graphitic quartzites. Either one apart from association with the other is easily identified. When it comes to gneisses, beyond the fact that some are assigned to the Grenville, I know absolutely nothing. Even intimate association does not settle the point. In this connection it is an open question in my mind whether or not the entire rock series at Mineville, exclusive of recognized eruptives, may not be classed as Grenville. The facts in the case are as follows. A diamond drill hole in the floor of Barton Hill was put down to a depth of 1,742 feet. Near the bottom of the hole graphitic white limestone about 7 feet thick shows with graphitic quartzite. In drill hole 263, 1,436 feet, the first 460 feet showed the Harmony and Old Bed deposits, below 1,300 feet the rocks were graphitic white limestones and graphitic quartzites. A drill hole put down 600 feet below the floor of No. 21 mine showed graphitic white limestone. For more than one mile, about two miles on strike, the Pilfershire and Lee mines are in white limestone. These mines are about two miles southeast of the Mineville ore beds. The dip from the limestone outcrops of these mines to the white limestone under Barton Hill is about 22°. Recognized Grenville outcrops a little more than one mile to the east of Mineville. East of Harmony B shaft, in the public road, graphitic quartzites are found in a large outcrop. It is thus a question in my mind as to whether the entire rock mass above the white limestones at Mineville, at least 2,100 feet thick from the crest of

Barton Hill to a depth of 500 feet below the lowest known ore body is not Grenville with injected sills of gabbro and syenite. In such an event, the fact that all of the Mineville mines are sulphur free would destroy any evidence to the end that sulphur is a distinctive characteristic of the Grenville magnetites. The Cheever mine north of Port Henry has shipped hundreds of thousands of tons of iron ore. It is practically sulphur free. It is in the Grenville white limestones. At least it lies between white limestone beds. My idea of a fair position to take is that in our present state of knowledge it is unsafe to say what is or is not a rock of the Grenville series outside of the safe limits which I have set.

Titaniferous vs. Nontitaniferous Magnetites.—Both Newland (ECON. GEOL., April-May, 1923, p. 291 et. seq.) and Miller (ibid., Dec., 1922, p. 712 et seq) question rather emphatically the reliability of the distinctive reliance which I place upon the presence or absence of titanium in the magnetic iron ores. Miller, in the reference quoted, seems to argue that I am wrong in even suggesting a sedimentary phase of the gray gneisses based upon titanium as a distinctive element. "The country rock of the ore at Lyon Mountain is certainly of igneous origin as proved not only by its more or less intimate penetration by an older dark gneiss (metagabbro) but also by its noteworthy developments of pegmatites and silexite phases." Is it going too far for me to be rather skeptical as to the value of "certainly proved" in the light of the following? In his paper on "Magnetic Iron Ores of Clinton County, New York" (Nov., 1919, ECON. GEOL., p. 517), "What appears to be true dikes of practically pure magnetite on small scales have been observed at a number of places. . . . The significance of dikes of magnetite is considered beyond in the discussion of the origin of the ores." The "beyond" is on page 528 et seq. Especially to the point is p. 531, par. 13—"The true dikes of practically pure magnetite with sharp contacts are probably the results of very late local intrusives of magnetic solutions of magnetite into congealed or almost congealed rocks."

In 1920 I made a very extensive examination and report on the Lyon Mountain Mines from Standish to Dannemora. I noted the "true dikes of practically pure magnetite" on Elbow Mountain, near Goldsmith and on First, Second, Third and Fourth Mountain. These mountains lie between Lyon Mountain and Standish. As Miller observes, "the dike" cuts across the well-foliated dark gneisses, only I should call the mass a pegmatite rather than a dike. Veins of the "dike" split the foliated rocks, cut across them in a very irregular manner. The "pure magnetite" occurs as isolated nodules in varying sizes from a hickory nut to over 100 pounds. As I estimated, the percentage of the magnetite would not exceed 10 per cent. of the entire mass, I was considering it as a possible mill ore. With this object still under consideration, I took a large general sample of the purest lumps and gave them to Mr. James Brakes, the Lyon Mountain chemist, for an exhaustive analysis. He reported as follows: Fe–61.5 per cent., Ti–6.66 per cent. The ratio of iron to titanium is, thus, 9.23 to 1. For comparison I took an analysis of the Lyon Mountain mill concentrates. This gave, Fe–60.13, Ti–0.15 per cent. In this sample the Fe–Ti ratio is 400 to 1. With the fact that the Lyon Mountain ore with only 97.7 per cent. of the iron of the "true magnetite dike" has yet 44 times more iron than has the dike ore with relation to Ti as the unit of measure, one is inclined to be skeptical as to a common origin, even allowing for Ti as titanite. The dike ore is certainly secondary to its rock host,—to me, it yet remains to be proved that the same is true of the Lyon Mountain ore body. I am quite sure that if Miller had painstakingly gone through the Lyon Mountain mines, studied the diamond drill cores, made sections from the maps and the drill cores, studied the outcrops carefully, from the "82" mine to the Parkhurst he would not be quite so sure of his conclusions as to the broken, interrupted structure of the ore body. The ore bodies have been most certainly folded and faulted since their formation, whatever their origin, and the wall rocks have certainly been faulted and folded with them. Newland is also evidently skeptical as to the value of titanium as a distinguishably

characteristic element, as between the igneous rocks and those whose origin is in question, as, for example, the gray gneisses. He misunderstands my attitude of mind with regard to the origin of the gray gneisses. "Nason implicitly regards the gray gneisses as sedimentary or Grenville." In my paper I deliberately choose the word "phase" and, according to the Century Dictionary, a "phase is the aspect, appearance, or guise; the aspect or presentation in which a thing of varying modes or conditions presents itself to the eye or mind." The gray gneisses are very evidently things of varying modes. The igneous phase has been extensively, almost exclusively, advocated for a long time, I simply choose to exploit another mode, the sedimentary one. Newland is quite skeptical as to the occurrence of titanium-free iron ores anywhere in the Adirondacks. As an appendix to this paper I am citing analyses of magnetic iron ores relative to their iron and titanium, including twenty-one analyses from the Ausable District and twenty-six from the Mineville District; and ten from the Crown Point District and other outlying mines. The majority of these are samples which I took personally or verified from check records. Titanium is altogether too obnoxious an element in an ore of actual or potential commercial value to be overlooked.

Without an exact arithmetical average, it will be noted that the maximum iron-titanium ratio of the gray gneiss ores is Fe, 590 to Ti, 1; the minimum is Fe, 97 to Ti, 1. On the other hand, the iron-titanium ratios of igneous rocks (gabbros etc.) run from Fe, 12.1 to Ti, 1 to Fe, 2.48 to Ti, 1 minimum. It will be noted that on the above basis of comparison the maximum iron-titanium ratio in the nontitaniferous magnetites is 49 times as much as in the titaniferous ores taking Ti as the unit of comparison. On the minimum basis, nontitaniferous iron is 97 as against minimum titaniferous, 2.48, the iron is 39 to one.

There are, however, several undetermined factors in the above which will stand in the way of a final conclusion either for or against Newland's position as well as my own.

In the first place the citations which I have made are from

commercial laboratories. The principal chemist is Mr. H. D. Gehret, the Laboratory that of Witherbee Sherman & Co. The analyses from the three operating mines represent literally millions of tons of ore either milled ore or crude (shipped as mined). So far as the concentrates are concerned, samples from daily mill runs or from car load shipments are taken. From these are weighed out a part for the determination of iron and phosphorus. The residue is emptied into a proper receptacle and at the end of 1, 2, 3 months or a year, a complete analysis is made. This checks up on the daily analyses.

Objections can rightly be made to basing Ti on concentrates. Ilmenite is nonmagnetic and, except for parts carried over mechanically into the concentrates, titanium would be eliminated in magnetic concentration. It thus follows that the Fe–Ti ratio, unless checked, is not a scientific criterion of relative amounts.

This check is furnished from the same mine from which the milling ore (ore bed) is taken. As the ore is raised from the mine it is dumped on a picking belt. From this is selected what is known as "Furnace" and "Lump" ore. The balance is sent to the mill, the Lump and Furnace, after careful sampling, is shipped as mined. It is really a "crude" ore, only rich enough to ship. Under "Old Bed Crude," it will be noted that the Fe–Ti ratio is 545 to 1; under "Old Bed C," concentrates after being milled, the Fe–Ti ratio is 500 to 1. The "Old Bed Crude" is not an isolated sample but represents shipments (in four years) of 806,529 tons. The analysis thus represents a yearly average of Ti of 201,382 tons.

There is another factor which, with his scientific fairness, he points out. I refer to the mineral titanite. This mineral is even more nonmagnetic than ilmenite. This mineral would thus tend to go into the tailings (rejects from magnetic separation) if present in the milling ore, some of it would appear in the concentrates, carried over mechanically. Since, in the commercial analysis Ti is the critical point at issue, not its combination, it follows that in the case of the "Old Bed Tails," with Fe 6 per cent. and Ti 1.81 per cent. the Fe–Ti ratio 3 to 1, it is quite prob-

able that titanite is almost wholly responsible for the high titanium content of the tailings. That it comes from the rock that is mixed with the milling ore, is indicated by the low Ti content of the "Lump" and "Furnace" ore which is shipped crude and shows only 0.11 per cent Ti. This Newland has pointed out generally. The above results are also in accord with Roesler's statement that Ti occurs in gabbros as ilmenite and in granitic rocks as titanite.

Whatever its scientific value, this is true in commercial practice. In the proposed opening of a new mine the three highly deleterious elements, P., S. and Ti, are carefully and repeatedly determined. Either of the above elements in excess of 1 per cent. are fatal unless they can be economically lowered or can be used as mixtures with other ores. These elements are usually determined irrespective of their rock hosts. In my extensive experience in the Adirondack fields I have persistently considered this factor. The results of this experience have proved, so far, to be commercially practical. It has taught me that a gabbro, anorthosite or a syenite magnetite is invariably uncommercially titaniferous; that a gray gneiss ore is not.

In all of the above examples cited, I must confess to a conviction that my conclusions are empiric and not at all scientific. But, to be perfectly frank, so far as I have read, I can but be convinced that the conclusions of other writers are entitled to no higher rank.

Appendix.

Titanium in the Mineville and Ausable Magnetites in the Gray Gneisses.

In the following table determinations of iron and titanium in concentrates are designated by C, crude ore by Cr. The number of analyses in the table is indicated by numerals 1, 2 etc.

Mine.	% Fe.	% Ti.	Fe–Ti Ratio.
Jackson Hill Cr.	62.20	0.38	166 to 1
3 Hogback C.	62.93	0.17	390 to 1
6 Hematite C.	63.54	0.00	
Gen. LaVake C.	62.33	0.25	249 to 1
8 Redgar C.	64.47	0.57	113 to 1
3 Battie C.	64.08	0.17	382 to 1
Cook Mt. Cr.	47.75	0.33	144 to 1
Cook Mt. C.	59.80	0.39	153 to 1
Cook Mt. Gen. C.	60.98	0.28	217 to 1
6 Palmer Hill C.	65.63	0.30	218 to 1
17 Jackson Hill C.	66.82	0.49	136 to 1
9 Jackson Hill C.	68.44	0.69	99 to 1
8 Jackson Hill C.	66.82	0.21	318 to 1

The above are from mines and prospects in the Ausable District; below are from operating and other mines in Mineville.

Old Bed C.	65.00	0.11	590 to 1
Old Bed Cr.	60.00	0.11	545 to 1
Old Bed Tails.	6.00	1.81	3 to 1
Harmony C.	65.00	0.16	406 to 1
Barton Hill C.	66.00	0.77	86 to 1
Smith C.	65.00	0.11	590 to 1

From the Crown Point District eight mines ran in iron crude, from 17 to 66 per cent. with no titanium except traces.

Seven mine openings immediately north of Mineville nonoperating but which have been mined many thousands of tons of ore show in concentrates Fe from 69.50 to 70 per cent., Ti, from 0.24 to 59 per cent., ratios varying from 117 to 1, to ratios of 290 to 1.

Miscellaneous Mines.

The following analyses are taken from *New York State Museum Bulletin*, No. 119, Albany, 1908.

Mine.	% Fe.	% Ti.	Fe–Ti Ratio.
Lyon Mountain Cr.	31.48	0.26	121 to 1
Lyon Mountain C.	60.13	0.15	400 to 1
Benson Mines Cr.	35.00	0.08	437 to 1
Benson Mines C.	60.00	0.11	543 to 1
Benson Mines Cr.	36.56	0.64	57 to 1
Benson Mines C.	62.24	0.64	97 to 1
Mt. Hope C.	61.90	0.27	225 to 1

Titaniferous Iron Ores in Gabbro or Gabbro Derivatives but Recognized as Igneous.

Lyon Mountain "Dike"	61.50	6.66	9 to 1
Littie Pond Cr.	41.57	11.29	4 to 1
Little Pond Cr.	29.87	7.84	4 to 1
Tunnel Mountain Cr.	35.99	9.87	3.6 to 1
Lincoln Pond Cr.	44.19	7.40	6 to 1
Split Rock Cr.	32.82	9.40	3.64 to 1
Diamond drill holes No. 181.	28.80	7.2	4 to 1
Harmony Mine Gabbro dike	28.00	7.0	4 to 1

Sanford Lake.	Singewald Ti ores U. S.		
Cheney Pit Cr.	40.33	9.46	4.4 to 1
Cheney Pit C.	62.15	5.0	12.1 to 1
Mill Pond C.	57.41	10.2	5.7 to 1
5 Sanford Hill C.	54.64	10.0	5.5 to 1
2 Sanford Hill C.	61.70	7.08	8.8 to 1
Iron Mt., Wyo. Cr.	47.13	17.02	2.77 to 1
6 Cumberland R. I. Cr.	32.23	13.07	2.48 to 1

Highest ratio in nontitaniferous magnetites, 590 to 1.
Lowest ratio in nontitaniferous magnetites, 57 to 1.
Highest ratio, titaniferous magnetites, 12.1 to 1.
Lowest ratio, titaniferous magnetites, 2.48 to 1.

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REVIEWS

Segregation Phenomena of Ore-forming Solid Solutions (Erzmischkristalle) and their Value in the Study of Ore Deposits and Ore Dressing. H. SCHNEIDERHÖHN, Metall und Erz, vol. 19, 1922, pp. 501–508 and 517–526.

The paper with this title appeared in the periodical *Metall und Erz* and seems to be of importance. The author attempts to show that some of our common ore minerals have structures that originated by the breaking up of solid solutions (Mischkristalle) when the temperature was lowered. The study of these structures in reflected light under high magnification, therefore, will lead to important conclusions as to the temperature of formation of the minerals. Especially will it be a sure guide to the recognition of certain primary minerals. However, the full benefit from these studies will be derived only after some systems of artificial sulphides have been investigated by the metallurgist and physicist.

In the first part of the paper theoretical pictures are considered. There are two reasons for the separation or segregation (Entmischung) of the components of a solid solution: (1) The lowering of temperature causes the lowering of the degree of solubility (in the solid state) of the components in one another. (2) One or more components, when pure, may be capable of forming two or more distinct crystalline substances—that is, they are polymorphous. This may lead to a variety of combinations in a system. Two of the examples mentioned are the system iron-carbon and iron-nickel. These and other examples mentioned are explained by phase rule diagrams. (An interesting paper by Rosenheim on solid solutions has recently appeared in *Trans. Am. Inst. Min. and Metal. Eng.*, 1923.)

The structures produced by the breaking up of the solid solution are discussed. A part of this discussion is based on the space lattice of the components. The main types of structure are:

(1) Emulsion structure. Segregations of submicroscopic to microscopic globules from the parent crystal.

(2) Cell, net, or mesh structure, due to the migration and accumulation of segregated globules to and at the boundaries of the crystalline grains.

(3) Lamellar or Widmannstätten structure. Plate and needle-like segregates arranged in the parent crystal according to structural planes

of the crystal. This structure may be explained by the probability that a part of the segregate can not escape to the boundaries of the crystal, partly because the speed of diffusion is too small, partly because the decrease in temperature is too rapid.

(4) The eutectic structure consisting of a very intimate grainlike or lamellar intergrowth of two (or more) new kinds of crystals. Examples of these four structures as they occur in natural and artificial substances, are given.

In the second part of the paper the author takes up some of the combinations of sulphides and oxides investigated by him or by other men, especially by American geologists. The illustrations (also reproduced in the author's new book "Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen . . . ," Berlin, 1922) are excellent.

The minerals are discussed in the following order:

Segregations of chalcopyrite in zincblende. Structures especially of type (1) and (2). Chalcopyrite separates as globules or lath-shaped particles along crystallographic lines of zincblende. These structures are especially common, if not universal, in zincblende of the "older generation." That they do not represent later chalcopyrite replacing zincblende seems to be practically proved by the discovery of these structures in a sulphide aggregate which had collected at the bottom of one of the furnaces of the Tsumeb mine in German S. W. Africa. In the ore itself of this district these structures of chalcopyrite were never seen. All veins of the "Rheinisches Schiefergebirge" show such structures in the older zincblende, while the younger well-crystallized blende does not show these inclusions. They are also present at Freiberg, Klingental, Georgental, Kapnik, Przibram, and in many American zincblende specimens. But in zincblende replacing limestone due to descending cold waters, the structures are always absent.[1] Therefore, the author concludes that they were formed at relatively high temperatures. ZnS, CuS, FeS, MnS, and CdS are soluble in one another to a considerable extent at high temperature, but on cooling CuS will segregate as $CuFeS_2$ while the other sulphides remain in the solid solution.

Segregations of stannite in zincblende. This occurrence is similar to the one just described. Stannite is arranged in the zincblende like chalcopyrite. Specimens from the Erzgebirge were examined.

Segregations of chalcopyrite and zincblende in stannite. Structures of the types (1) and (2) were found in all but one specimen of stannite examined. (See also: Reinheimer, *Neues Jahrb. f. Min.*, 1922, and Schwartz, *Am. Mineralogist*, 1923, p. 162—J. W. G.) It seems to be

[1] Teas found the same relationship. Trans. Am. Inst. Min. Eng., vol. 59, 1918, pp. 68–87.

pretty certain, therefore, that ZnS, CuS, FeS, SnS form a solid solution at higher temperature. Decrease of temperature causes the expulsion of $CuFeS_2$ and ZnS, exactly as ZnS expelled $CuFeS_2$ with decrease of temperature.

Segregations of argentite, argentiferous tetrahedrite, and ruby silver in primary galena. Argentite is the most common of the three minerals in galena, though the other two are found in some districts. The structure types (1), (2), and (3) may be observed, but only in primary ores. (The author refers to ECON. GEOL., 1915, p. 172, and p. 462, and to 1917, p. 297.) Structures found in deposits formed by descending waters are quite different. (See, for example: G. Berg, *Metall. u. Erz*, 1921, p. 321–326. Berg's ideas are not shared by Schneiderhöhn.)

Segregations of covellite in chalcocite. The author has had no opportunity to see ores of this kind, but refers to papers and illustrations by Turner and Rogers (ECON. GEOL., 1914) and Tolman (*Trans. Am. Inst. Min. Eng.*, 1916). In both cases those authors think the ores primary.

Segregations of chalcopyrite in bornite. Again reference is made to papers by American authors. (Overbeck, ECON. GEOL., 1916, Bateman and McLaughlin, ECON. GEOL., 1920.) Schneiderhöhn himself found minute chalcopyrite lamellæ parallel to crystallographic directions in artificial bornite in one of the furnaces of the Tsumeb mine.

Segregations of sulphides from basic magmas and segregations of pentlandite in pyrrhotite. Basing his conclusions on those of J. H. L. Vogt, the author believes that part of the sulphides segregate from the magma while in the molten state. The collecting of the sulphides along the boundaries of the silicate grains, forming a net or mesh structure, indicates this. The Sudbury sulphides are of this type. Segregations of pentlandite from pyrrhotite in those ores seems to be a later process, however, which took place *after* solidification of the sulphides. A cell or mesh structure of pentlandite surrounding pyrrhotite resulted.

Doubtful cases of sulphide intergrowth. Several paragraphs deal with such structures as graphic intergrowths of sulphides, which have been thought true intergrowths by some and replacements by others. The author thinks it possible that some are segregations, especially those minute structures which can be seen only with very high magnification.

Ilmenite, and ilmenite and spinel, in magnetite. Also hematite in ilmenite. Here are discussed the well-known structures parallel to crystallographic directions of magnetite.

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The Occurrence and Uses of Peat in the United States. By SOPER, E. K., and OSBON, C. C. United States Geological Survey, Bull. 728, pp. 207, pls. 18 (10 maps), Figs. 32 (31 maps).

This report covers practically all the valuable peat areas in the United States, as well as nearly all the swamp lands, and is a valuable compilation of the data on peat for the whole country. The estimated resources of peat, computed on an air-dried basis are 13,827,000,000 short tons, or a little more than that formerly estimated. Of the states containing valuable deposits Minnesota contains by far the largest quantity with Wisconsin, Florida, and Michigan following in order. Although there is so much peat in the country the annual production is comparatively small, only a little over 30,000 tons. The average value per ton for the year 1921 was $8.55. The chief use for peat is in agriculture. It is used in the raw state or in prepared fertilizers because of its nitrogen content, which runs from 1 to 4 per cent. and averages about 2 per cent. There are other minor uses for it in this country, such as stock feed, packing, and fuel and it is suggested that the United States might utilize to advantage some of the large deposits, well situated for exploitation, in the way that similar deposits are used in some of the countries of Europe. It is stated that peat coke is extensively used in Europe but not at all in America, although it could probably be produced here for about $4.00 a ton. Powdered peat has been experimented on in this country and found to be quite satisfactory for certain powdered-fuel purposes but so far it has not been adopted in practice.

Concerning the cost of producing peat for the market not much is said in the report beyond the quotation of the figures secured by the Department of Mines of Canada from experiments carried on previous to the year 1914. The figures for the cost of operating a few of the larger plants in the United States would have been interesting and valuable to many readers in throwing further light on production costs.

Brief discussions of the origin and the characteristics of peat are presented and a collection of analyses, partly new and partly compiled from other works forms a valuable part of this work. Peat deposits are classified according to the topographic conditions under which they originate and again as floral types. The authors recognize three topographic types and eight floral types of deposits. They also make four divisions on a basis of physical characters, these divisions comprising *turfy, fibrous, carthy,* and *pitchy* peats. The greater portion of the bulletin is taken up with the descriptions, necessarily brief because of the vast number of deposits involved, of deposits scattered from the Atlantic to the Pacific. The numerous maps accompanying these descriptions add much to their value and those interested in the peat resources of the country will find this bulletin a very useful addition to our literature on peat.

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Die Kohlenlagerstätten Russlands und Sibiriens. (The Coal Deposits of Russia and Siberia.) By S. V. BUBNOFF. Berlin, Gebrüder Borntraeger, 1923, pp. viii + 244.

The growing interest of late in the mineral resources of Russia and their possible economic development makes this timely treatise on Russian coals of value both to the geologist and to those interested in the development of coal. The book contains little original material; it is a compilation in one volume of information to date on the geology and stratigraphy of each coal basin or region, the kind of coal, the condition of the mines, and the economic condition of each district. Each section is followed by a complete bibliography, including references of 1921 and the early part of 1922. This feature alone is of value to geologists in bringing together numerous scattered references to the little-known Russian coals. The book is not intended as an exhaustive treatise but rather as a reference and guide book. In this it serves a useful purpose.

In general this treatise may, from the standpoint of the reviewer, be divided into three parts. The first part treats of the various features involved in a discussion of coal. Here the author considers the general extent and occurrence of the different coals including the Carboniferous, Mesozoic, and Tertiary beds. In an excellent table the age relation of the Carboniferous coal horizons of Russia and western Europe are compared. This is followed by a valuable discussion of the geologic structure of the Russian fields.

In the second part or bulk of the book are discussed the individual coal basins or coal fields including the following:

1. The Donetz basin.
2. The Moscow basin.
3. Northern Russia.
4. Lignite of Southern Russia.
5. Caucasus, Krim, and Caspian Region.
6. Coal of the Urals.
7. Coal of Turkestan.
8. The coal beds of the Kirghiz-Steppes.
9. The Kusnezk coal basin.
10. The bituminous coal beds of Minusinsk.
11. The remaining coal beds of western Siberia.
12. The coal basin of Irkutsk.
13. Lignite deposits of Trans-Baikal.
14. The coal beds of the Jakutsk region.
15. The coal beds of the Amur region.
16. Coal of the Coast Province.
17. Coal of Sakhalin.

The Donetz basin is the most important of the Russian coal fields and the author includes considerable detail in the 50 pages of discussion allotted to it. Among other things he discusses the general geology and structure of the region, the coal seams and their stratigraphic position, the character and composition of the coal, the coal reserves, transportation, and other economic conditions. The Moscow basin, the Kirghiz-Steppes, the Urals, and the Kusnezk basin are likewise treated in some detail, whereas the other regions are more briefly discussed.

The last part of the book, covering 23 pages, is devoted to a general consideration of the reserves, the output, and the "fundamental principles of the Russian coal industry." The author raises the estimated reserves of Russia from 238,985,000,000 tons given in 1913 to 474,099,000,000 tons. This increase is largely accounted for by the great increase in reserves allowed the district of Kusnezk which is from 13,625,000,000 to 250,000,000,000. But the estimated reserves for the Moscow, Urals, and the Kirghiz-Steppes have also been somewhat increased over the 1913 estimates.

The reviewer has little to criticize. The book is well proportioned and emphasis is placed on the more important fields. One feature, however, that could have been improved is the figures, and more geologic sketches and diagrams would be of advantage. The book could also afford a more substantial binding. But it well serves the purpose for which it was written and is recommended to those interested in coal, and in the Russian fields.

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SOCIETY OF ECONOMIC GEOLOGISTS

The Society of Economic Geologists is to hold its Annual Spring meeting in New York City, May 23d and 24th. Papers will be presented at morning and afternoon sessions, May 23d, at Room 308, Schermerhorn Hall, Columbia University, 116th Street, New York City.

A dinner will be held at the Harvard Club, after the above meetings.

On May 24th an excursion will be made to Franklin Furnace, New Jersey, to study the open cuts and surface geology of the mines of the New Jersey Zinc Company at both Mine Hill and Sterling Hill.

Mr. Arthur Notman, 170 Broadway, New York City, is Chairman of the Arrangements Committee.

Professor James F. Kemp, President of the Society, was elected member of the Board of Directors of the Economic Geology Publishing Company for the year 1924 at the stockholders meeting of the company held March 3, 1924.

SCIENTIFIC NOTES AND NEWS

Frederick L. Ransome, who has been in charge of the section of metalliferous deposits with the U. S. Geological Survey since 1912, and who has during the present college year held the position of Professor of Economic Geology in the University of Arizona at Tucson, while on leave of absence from the Survey, has accepted permanently the chair of Economic Geology at the University of Arizona and will resign from the U. S. Geological Survey.

A. C. Lawson was a recent visitor in New Haven.

M. R. Campbell, of the U. S. Geological Survey, has recovered from a prolonged attack of asthma and has returned to his work.

C. K. Leith, of the Department of Geology in the University of Wisconsin, gave a course of six lectures on structural geology at Columbia University, New York, between February 21st and March 1st.

Willard Rouse Jillson has been reappointed director and state geologist of the Kentucky Geological Survey for a 4-year term beginning April 1, 1924.

Sidney Paige, of the U. S. Geological Survey, of Washington, D. C., was married on March 1 in New York City to Frances, daughter of Mr. Henry Clay Hall.

Victor Monnett is acting head of the Department of Geology of the University of Oklahoma.

Loftus Hills, previously government geologist of Tasmania, has established an office in London as consulting geologist.

M. I. Goldman of the U. S. Geological Survey attended the meetings of the American Association of Petroleum Geologists in Houston, and stopped at Shreveport to collect specimens in connection with studies of salt-dome petrography. After the meetings he remained in the vicinity of Houston to collect specimens.

C. H. White, of San Francisco, formerly a member of the Harvard faculty, was in Washington recently conferring with a group of Survey geologists interested in metalliferous problems.

Charles Schuchert, of Yale University, who has been visiting since

Christmas time different parts of the southern and southwestern states, has returned to New Haven.

Walter Harvey Weed recently visited the Porcupine gold field, in Ontario, where he inspected the McIntyre, Ankerite, and Paymaster mines.

Waldemar Lindgren was a recent visitor in Washington and New Haven.

Percy E. Raymond, Associate Professor of Paleontology at Harvard University and curator of the Agassiz Museum, will have charge this year of the Harvard Summer School of Geology, which he will take to the Canadian Rockies.

Willet G. Miller sailed in April for England.

Franz Beyschlag has retired after serving forty years as president of the geological survey of Prussia and of the neighboring federal states. He is well known for his work on ore deposits, as the author of a text book of economic geology, and as editor of the *Zeitschrift für praktische Geologie*. He is succeeded by Paul Krusch.

H. D. Miser, of the U. S. Geological Survey, is working on a geological map of Oklahoma, with headquarters at Norman.

W. W. Rubey and N. W. Bass have joined Mr. Bramlette in coöperative work on oil and gas in Kansas. Mr. Rubey has charge of the work.

J. E. Spurr, editor of the Engineering and Mining Journal-Press, gave a series of three lectures on Ore Magmas before the Geological Department of the University of Wisconsin March 5th to 7th. During the same week there was a conference at Madison on Lake Superior geology, participated in by the members of the Geological Department of the University of Wisconsin, representatives of the Michigan and Minnesota geological surveys, and mining geologists from various parts of Lake Superior.

E. W. Berry, of Johns Hopkins University, addressed the Petroleum Club of the U. S. Geological Survey in Washington, D. C., on climates of the coal periods.

Hoyt S. Gale is now located in Los Angeles.

H. A. Guess, of the American Smelting and Refining Co., is in Trujillo, Peru, where the company has mining property.

H. T. Hamilton, former manager of the Moctezuma Copper Co., is associated with Ira B. Joralemon as consulting mining engineer in San Francisco.

Joseph H. Sinclair has returned from the Republic of Guatemala where he has been making geological oil examinations.

C. L. Dake, Professor of Geology at the Missouri School of Mines and Metallurgy, spoke before the Tulsa Geological Society, Tulsa, Oklahoma, on February 16th on "The Ozark Uplift."

C. E. Crawford is in Guanajuato, Mexico, where he will be engaged in geological work for two months.

Julius Sanchez, who has been working for the state of New Mexico on mineral land classification, is now with the U. S. Bureau of Mines as geologist on petrographic work.

Walter W. Scott, deputy supervisor of the Department of the Interior for oil and gas operations in the Gulf Coast district, has been transferred to a similar position in the Rocky Mountain district, with headquarters at Casper, Wyoming.

W. Armstrong Price, who has for the last year been engaged in consulting oil and gas geology in the Appalachian fields with headquarters at Clarksburg, West Virginia, spent March and April in field work in northern Mexico.

Robert H. Wood and Virgil O. Wood, petroleum geologists, have removed their offices from 816 Daniel Building to 302 Commercial Building, Tulsa, Oklahoma.

J. J. Sederholm, director of the Geological Survey of Finland, invites geologists interested in the problems of the Pre-Cambrian rocks to visit the islands and coast near Abo in southwest Finland for a 3-day excursion in the early part of June.

The Rocky Mountain Association of Petroleum Geologists has elected the following officers for this year:

Thomas S. Harrison, president,
Carroll H. Wegemann, first vice-president,
F. F. Hintze, second vice-president,
Charles M. Rath, secretary-treasurer.

Hans von Höfer died in Vienna February 9, 1924, at the age of eighty years. His life was devoted to a systematic study of geological problems, and he published a number of books written in German. These include *Taschenbuch für Bergmänner, Grundwasser und Quellen, Die Verwerfungen, Anleitungen zum Geologischen Beobachten, Kartieren und Profilieren, Petroleumindustrie Nordamerika's, Das Erdöl und Seine Verwandten,* the second volume of *Das Erdöl,* by C. Engler and von Höfer, and a number of articles in periodicals and professional papers. During the last months of his life Dr. von Höfer carried on an investigation of the carnotite, molybdenite and roscoelite resources of Colorado for the Austrian steel interests.

The annual stockholders and directors meeting of the Economic Geology Publishing Co. was held in Washington last month. Professor Kemp and K. C. Heald were elected directors of the company.

In Tampico, Mexico, a group of geologists meet on the first and third Wednesdays of each month for an informal luncheon at the Imperial Hotel. The attendance varies from 15 to 25. At a recent luncheon there were present H. F. Nash, A. W. Noble, John M. Muir, D. A. Powell, P. H. Bohart, S. A. Grogan, R. Leibensperger, W. A. Baker, Sr., Bruce Wade, John Bell, Donald Bell, S. W. Lowman, S. R. Saye, L. G. Putnam, C. L. Griffith, E. Dissinger, E. Braendlin, Ben C. Belt, E. Ordonez, R. C. Stoner, Emil Böse, Walt M. Small, and J. B. Dorr. George Blardone, Palmer Beckwith, and C. Leibensperger were present as guests.

The Canadian Mining Institute held a well attended annual meeting at Toronto, Ontario, March 5–8. Among the papers presented of interest to geologists were: Mineralography as an Aid to Mining, by Ellis Thompson; The Value of Topographical and Geological Maps, by K. G. Chipman; Some Economies Effected on Canadian Mining Statistics, by S. J. Cook; The Minto Coal Basin of New Brunswick, by W. S. Dyer; Oil and Gas in Ontario, by R. B. Harkness; Sodium and Magnesium Salts of Western Canada, by L. Heber Cole; The Iron Ore Situation in Ontario, by G. W. MacLeod; Developing Zinc and Lead Deposits in Gaspé Peninsula, by J. C. Beidelman; Developments in the Quebec Gold Belt, by W. M. Goodwin; A New Oil Well in Romney Township, Kent County, Ontario, by H. R. Davis; The Mineral Wealth of the Pre-Cambrian, by C. V. Corless; Manitoba's Contribution to Canada's Mining Opportunities, by R. C. Wallace; and The Mineral Industries—Their Present Place in the Commercial Development of Canada, by Charles Camsell.

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